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Evaluation and prediction of maize response to early-season injury from stalk borer

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to early-season injury from stalk borer

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INTRODUCTION

During a growing season, corn plants are stressed by injuries from many diverse pests that will ultimately reduce corn productivity. In the North Central Region, considerable attention has been directed toward a number of insects that reduce corn yields: in particular, the corn rootworm complex, the European corn borer, and more recently, the black cutworm. Much information regarding biology, population dynamics, damage syndrome, and management tactics have already been developed for these species, thereby reducing their immediate threat. However, with the trend toward corn production systems that include methods of conservation tillage, new pest problems have emerged. Few answers are available for many of these problems, prompting an urgent need for basic information to develop pest management programs designed specifically for reduced-tillage systems. One such pest that is rapidly growing in importance and for which we lack basic information is the stalk borer, *Papaipema nebris* (Guenée).

The extent and manifestation of injury to corn by stalk borer is still largely unknown. Direct losses may be sustained through reduction in plant populations and an increase in weakened and barren plants. The stalk borer problem is not expected to subside naturally. Indeed, it is expected to increase with increased acceptance of corn production systems utilizing conservation tillage and no-tillage.

Consequently, research needs to be conducted on all aspects of stalk borer tunneling, yield losses, and management strategies. Knowledge of the growth and yield response of popular corn varieties relative to the time and severity of stalk borer attack is critical to the development of decision rules and pest management strategies for stalk borers infesting conservation-tillage systems. Without such knowledge and more efficient pest management tactics, losses can be expected to increase significantly.

Consequently, the main objectives of my research were to:

(1) Quantify the effect of time of stalk borer attack relative to corn development on plant growth and yield (Sections I, II, and III).

(2) Determine the yield-loss function and calculate economic injury levels and economic thresholds (Sections III and IV).

(3) Evaluate the use of development and migration models to improve the timing of insecticide applications (Section V).

(4) Integrate available information on stalk borer phenology, population dynamics, and yield losses into a simulation model which could be used to evaluate management strategies and predict final grain yield in stalk borer infested fields (Section VI).

LITERATURE REVIEW

Description of Species

The stalk borer, Papaipema nebris (Guenée), is native to North America and ranges from the Atlantic coast west to the Rocky Mountains and from southern Canada and the New England states south to the Gulf of Mexico (Decker 1931). Young larvae possess a characteristic purplish thorasic band and longitudinal purple and white abdominal stripes (Decker 1931). Purple markings fade to white in older larvae. When full grown, larvae average 30 mm in length. The heavy-bodied moths tend to be a fawn-gray to brown color. Moths possess a tuft of white-tipped scales at the base of each antennae. Two color forms have been described. The light-phase form has white claviform, orbicular, and reniform spots on the forewing. In contrast, the spots of the dark-phase form are obscure or represented by indistinct smoky areas. Wing span ranges from 25-40 mm.

Phenology

The life cycle is characterized by a single generation per year. Moths oviposit eggs during the fall and prefer to oviposit between the stem and leaf sheath or in rolled and folded leaves of grasses (Decker 1931, Levine 1985). Stalk borer eggs overwinter on grasses (Forbes 1905, Smith 1905), and young larvae hatch during late April and May. Larvae initially feed on grasses, such as smooth brome, (Bromus inermis Leyserra), bluegrass (Poa pratensis L.), orchardgrass (Dactylis glomerata L.), and timothy (Phleum pratense L.) (Decker 1931, Stinner et al. 1984). Young larvae tunnel at or just above the soil surface into the stems of plants (Decker 1931). Eventually, tunneling larvae cause infested grass stems to wilt and turn brown (Decker 1931, Davis and Pedigo 1989).

Stalk borer larvae can not complete development on small-stemmed grasses. Constraints of stem diameter and the eventual tunneling of the entire stem force young larvae to migrate to a second host. Most often, the second host is a broadleaf plant such as giant ragweed (Ambrosia trifida L.). However, stalk borers have been reported to feed on over 176 different species of plants, including corn (Zea mays L.) (Decker 1931). Migration in search of a suitable host plant usually occurs when larvae are fourth to sixth instars (Lasack and Pedigo 1986). Typically, movement extends over a period of several weeks. Capture of larvae in pitfall traps indicated that movement out of smooth brome terraces begins ca. 600 centigrade degree days (CDD) (accumulated after 1 January, base temperature 5.1°C), peaks at ca. 900 CDD, and ceases after 1100 CDD (Lasack and Pedigo 1986). Where infestations occur in terraces and field edges, movement out of grasses to a second host, such as corn, is restricted to the 8 rows closest to the grass (Levine et al. 1984). Bailey (1985) found that the density of larvae in corn (Y) was related to the row position (X) through the equation

$$Y = -0.553 + 7.902/X$$

where row 1 is located closest to the grassy area. However, if eggs are laid on grasses within a field, injury to corn may be more widespread (Stinner et al. 1984).

When food quality is good, larvae complete development woth seven to nine molts (Lowry 1927, Decker 1931). By mid-July, mature larvae either desert the plant and form a small oval cell just below the soil surface or remain in the plant to form a cell at the bottom of the burrow (Decker 1931). Subsequently, larvae pass into a prepupal stage, lasting one to six days, before pupating. Moths begin emerging in mid-August. Collections of moths from light traps indicated an extended flight period from mid-August through mid-October in Iowa (Decker 1931, Bailey et al. 1985a). Males constituted 89.3% of the trap collections (Bailey et al. 1985a). Multiple matings by female moths were common, and up to seven spermatophores were observed.

Development and Degree-day Modeling

Studies in central Illinois showed that egg diapause terminates by 15 January (Levine 1986). Egg development under constant-temperature regimes indicated that post-diapause development is a function of temperature above a minimum of 8.9°C (Levine 1986). Although Levine (1983) previously reported that 50% egg hatch occurred after 182.6 CDD (base temperature 8.4°C) had accumulated, a second series of studies showed that 50% egg hatch required 209.5 CDD (base temperature 8.9°C) (Levine 1986). The discrepancy was attributed to partial development of eggs stored outdoors before the first series of growth chamber studies were initiated (Levine 1986).

To evaluate stalk borer development from egg to adult, a developmental minimum of 5.1°C was proposed (Levine 1983). Levine (1983) found that degree-day accumulations from 1 January required for 50% hatch, pupation, and moth emergence were 256.8, 1,517.0, and 1,946.8

CDD, respectively. To test the validity of these accumulations for predicting stalk borer phenology in the field, Lasack et al. (1987) conducted an extensive sampling program of natural stalk borer infestations. From these data, the proportion of larvae that had reached or exceeded a given stage of development was modeled by using a series of logistic functions for larval stages one through eight. One method for estimating egg hatch is to determine the appearance of first instars in the field. Fifty percent development of first instars occurred at 403.7 and 341.1 CDD (base temperature 5.1^{o}C, accumulated from 1 January) in 1984 and 1985, respectively. Although development at alternating temperatures has been reported to accelerate development in some insects compared to constant-temperature regimes (Hagstrum and Hagstrum 1970, Kaster and Showers 1984), development of stalk borer larvae in the field took longer than predicted by growth-chamber models. Lasack et al. (1987) proposed that rainfall reduced temperatures near the ground, where the eggs are developing, compared to air temperatures. This may have caused an over estimation of accumulated degree days. Predictions from growth-chamber studies were closer to actual accumulations in a fairly dry spring (1985) than to accumulations during a wet spring (1984).

In the field, several different stages may be present at the same time. Overlap in stages is small for early instars, but becomes very pronounced later in the season when as many as four larval stages may be present at the same time (Lasack et al. 1987). However, development in the field is not strictly a function of temperature. Field studies have shown that late-instar development, pupation, and moth flight strongly coincide with Julian date (Decker 1931, Bailey et al. 1985a, Lasack et al. 1987). In a study conducted by Lasack et al. (1987), comparison between years for 50% development of early larval stages indicated a difference of 28 days. Subsequently, stadia lengths for stages four and six required 82.5% and 60.2% more degree days, respectively, in a warm year (1985) than in a cool year (1984). Thus, by the time larvae were seventh instars, 50% development in 1984 occurred six days later than in 1985, but required 108 fewer degree days. In a three-year study, Decker (1931) observed that pupation took place from 17 July through 29 August and had a maximum variation of three days. Finally, Bailey et al. (1985a) reported that 50% flight occurred during the period from 8-14 September. The degree-day model proposed by Levine (1983) predicts 50% flight at 1,947 CDD (base 5.1°C). However, Bailey et al. (1985a) found an average of 2,393 CDD were required.

Dispersion and Sampling

Davis and Pedigo (1989) evaluated the distribution of larvae within grassy, noncropped areas and in neighboring rows of corn by using Taylor's Power Law and Iwao's mean crowding regression. The distribution of young larvae in the grass tends to be aggregated, as indicated by the coefficients b and β both being greater than 1.0. This initial aggregation pattern was attributed to ovipositional behavior of female moths, which tend to lay eggs in groups of 10 or more. The coefficient, α, of Iwao's mean crowding regression, has been termed an "index of basic contagion" and indicates the size of the clump. The value of α varied during the study, being equal to 0.29 in 1984 and 2.05

in 1985. Davis and Pedigo (1989) hypothesized that heavy rainfall during egg hatch reduced the number of larvae which survived from each egg mass, thereby reducing group size.

Distribution of larvae in corn was evaluated at two levels, intrarow (between plants) and interrow (across rows). Analysis of stalk borer dispersion in corn revealed that the intrarow spatial distribution radically changed when larvae began to move into the corn. Larvae that attacked corn plants as a first host were distributed uniformly within a row, as indicated by β and b values of less than one. Later in the season, invading larvae that moved from grassy areas altered the observed dispersion. The values of b and β rose above one, indicating a clumped or aggregated distribution of larvae. As population density declined, larvae assumed a more random-to-uniform distribution. The coefficient, α, indicated a tendency for a repulsive interaction between larvae, which tended to equalize the number of larvae inhabiting each plant (Iwao and Kuno 1971).

Dispersion across rows tends to be aggregated (Davis and Pedigo 1989). Highest densities typically are found in the rows nearest a grassy area and density declines as distance from grassy areas increases (Bailey 1985).

Using information on dispersion, Davis and Pedigo (1989) developed sequential count plans for estimating stalk borer density within noncropped areas and within corn. Because sampling stalk borers in grass is very labor intensive, Davis and Pedigo (1989) recommended sampling these areas when larvae are mostly third instars (500-600 CDD, base temperature 5.1^{o}C). At this time, grass stems infested with larvae appear wilted and browned, a condition called "dead heart". By selecting grasses with dead heart, the time required to estimate densities in noncrop areas can be substantially reduced.

Mortality Factors

Several morality factors have been implicated in reducing stalk borer densities. Lasack (1986) reviewed the known parasitoids that were reported before 1984. Although Decker (1931) suggested that parasitization was an important mechanism for regulating stalk borer numbers, later collections in Iowa and Ohio suggested that parasitism rates were fairly low (Lasack et al. 1987, Felland 1990). In samples collected from corn and ragweed in Iowa, a complex of three species, Campoletis oxylus Cresson (Hymenoptera: Ichneumonidae), Lissonota brunnea Cresson (Hymenoptera: Ichneumonidae), and Gymnocheta ruficornis Williston (Diptera: Tachinidae), parasitized fewer than 3% of the larvae collected from late April through mid-July during a two-year period (Lasack et al. 1987). C. oxylus was the major parasitoid of instars one through five during a warm spring (1985) when stalk borers hatched in late April. However, in a cool spring (1984) when stalk borers hatched in mid-May, L. brunnea was the primary parasitoid. G. ruficornis was collected from instars six through eight during both years. In Ohio, collections in 1979 and 1980 indicated that parasitism varied by host plant, averaging 15% in corn, 2.2% in potatoes, 12.1% in common ragweed (Ambrosia artimisiifolia L.), and 3.4% in giant ragweed (Ambrosia trifida L.) (Felland 1990). Major parasitoids in Ohio collections were Lixophaga thoracica (Curran) (Diptera: Tachinidae),

<u>Sympiesis</u> <u>viridula</u> (Thompson) (Hymenoptera: Eulophidae), <u>L</u>. <u>brunnea</u>, and <u>G</u>. <u>ruficornis</u>.

Partial life tables for larval stages one through seven suggest that mortality rates are very low for larvae tunneled in grasses, with less than 20% mortality observed during a two-year period (Lasack et al. 1987). However, migrating larvae are vulnerable to both environmental factors and predators. In 1984, stage-specific mortality rates averaged 49.1% for fourth instars and 46.9% for fifth instars. In 1985, mortality rates were higher and averaged 57.1% for fourth instars and 81.9% fifth instars.

During migration, larvae may be vulnerable to several predators such as spiders, ants, carabids, small mammals, and birds (Lowry 1927, Decker 1931, Stinner et al. 1984, Lasack et al. 1987). No attempt has been made to quantify the effectiveness of these predators in reducing stalk borer numbers. In addition, rainfall during egg hatch has been linked to high mortality of young larvae (Decker 1931, Lasack et al. 1987, Davis and Pedigo 1989). Decker (1931) also suggested that hot, dry weather may cause egg desiccation and larval dehydration.

Injury to Corn

The stalk borer's polyphagous feeding habit has contributed to the species' role as an important, although sporadic, pest of many cultivated crops, including corn, wheat, and vegetables. During the late 1800s and early 1900s, stalk borer injury to crops, especially to field corn, was so significant that the stalk borer was mentioned as one of the principal insects of the year in the Yearbook of the Department of Agriculture from 1902 to 1908 and listed as one of the ten most destructive insects of the year in the 1927 Insect Pest Survey (Decker 1931). With the advent of improved herbicides combined with conventional-tillage practices, stalk borer damage was limited to scattered corn plants bordering field edges and waterways. In recent years, however, the situation has reversed, with stalk borer becoming a sporadic, but serious pest throughout the Midwest in conservation-tillage fields (Rubink and McCartney 1982).

Field corn is usually attacked as a second host when plants are two inches to two feet tall (Lowry 1927, Decker 1931. However, young larvae may infest corn as a first host under certain conditions. In no-tillage and reduced-tillage fields, especially those fields with poor grass control the preceding fall, stalk borer infestations can become quite heavy. If burn-down herbicides are applied before egg hatch, newly-emerged larvae will feed on the only green growth available, seedling corn plants (Levine et al. 1984). Two types of injury to young corn have been described (Lowry 1927, Decker 1931, Bailey and Pedigo 1986). Larvae may enter the top of the plant and feed within the whorl. As the leaves expand, irregular rows of ragged holes become visible. If larvae continue to tunnel into the plant or if attack is initiated by tunneling into the base of the stem, the center whorl of leaves may become completely cut off. In this instance, the plant wilts above the point of attack and exhibits typical "dead heart" or "flagging" symptoms. If the corn plant survives the attack, it may send out new shoots or "tillers" (Levine et al. 1984, Bailey and Pedigo 1986). Severely damaged plants often appear stunted and deformed.

In recent years, several investigators have studied the effect of stalk borer injury on regrowth and yield components. Levine et al. (1984) examined the regrowth capabilities of individual corn seedlings injured by natural infestations of larvae. They found that seedlings injured earlier in development produced fewer harvestable ears and less grain than plants injured later in development. In addition, 58.1% of the plants not producing a harvestable ear survived until harvest. Nonproductive plants were thought to continue to compete for sunlight, moisture, and soil nutrients. When attacked after the eight-leaf stage, corn plants showed little, if any, yield loss. One problem in using natural infestations, however, is that many extraneous variables, such as plant population, hybrid, infestation level, and the limited number of plant stages attacked in a given field, make quantification of yield-loss relationships very difficult.

In another study, Bailey and Pedigo (1986) infested field corn with second to fourth-stage larvae. Damage to two- to four-leaf corn was categorized as uninfested, leaf feeding, or dead heart. Although grain and cob weights from plants sustaining dead-heart damage were significantly lower than those of uninjured plants, tissue yields from plants with only leaf-feeding damage were not significantly reduced. Lower yield for dead-hearted plants was attributed to a lack of reproductive synchrony, which reduced pollination and increased numbers of barren stalks. Bailey (1985) also monitored stalk borer infestations adjacent to brome grass terraces. He found that an increase in larval number produced a linear increase in percent reduction in plant population, as well as a quadratic increase in percent barren plants.

Overall yield declined an average of 3.7 bushels per acre for each stalk borer found in a 1/200-acre sampling area. Plants with dead-heart yielded 19%, 32%, and 39% lower for stalk, cob, and grain yields, respectively.

Management Strategies

A wide range of management strategies have been proposed and evaluated to reduce the impact of stalk borers on grain yield. Decker (1931) recommended burning of field edges and other grassy areas from 1 November through 1 May. Burning noncropped areas effectively reduced stalk borer injury to neighboring corn rows by 85-90% in a two-year study. However, restrictions on burning may not make this a feasible alternative. Other preventative strategies include elimination of large-stemmed weeds such as giant ragweed from fence rows, mowing grassy areas during the second week in August in order to reduce ovipositional sites, and suppression of weedy grasses within fields when moths are ovipositing (Decker 1931). Research conducted in Illinois suggested that tillage or burndown of grassy weeds could significantly reduce stalk borer infestations (Illinois Natural History Survey Report 1986). In contrast, no-tillage practices favor the survival of stalk borers. However, even without the presence of green vegetation at egg hatch, stalk borer larvae were observed to survive a short period of time until the crop emerged.

The affect of hybrid selection and altering planting decisions, such as planting date and population, have received little attention. Peterson et al. (1987) evaluated several inbred lines, which possessed varying degrees of resistance to European corn borer, for resistance to stalk borers. A reduction in damage severity was detected; however, more research in this area is needed before recommendations can be made.

Currently, Iowa extension recommendations for management of stalk borers in reduced-tillage fields suggest the use of an insecticide spray following the application of a burndown herbicide. The insecticide should be applied after the grass has turned brown, but before corn has emerged. Some success has been obtained by tank-mixing insecticide with a fast-acting herbicide. However, insecticides are not recommended to be applied before May 10. One problem with these recommendations is that neither stalk borer populations or timing of egg hatch are considered in the decision to apply an insecticide. For example, Lasack et al. (1987) found that time of egg hatch shows considerable variability between years. Fifty percent hatch in central Iowa during 1984 and 1985 occurred ca. 23 May and 29 April, respectively. Application of an insecticide at or shortly following planting would have been ineffective in fields planted before mid-May in 1984. In 1985, larvae that eclosed from eggs laid within the field potentially could have caused considerable injury to corn if planting occurred before 1 May. Although recommending that no insecticide be applied before 10 May might be a good rule of thumb, it may not be the best option in all years.

SECTION I.

IMPACT OF STALK BORER (LEPIDOPTERA: NOCTUIDAE) TUNNELING ON INTERNODE ELONGATION AND GRAIN YIELD IN CORN

ABSTRACT

The distribution of stalk borer (*Papaipema nebris* (Guenée)) tunnels and their impact on stalk elongation and grain yield in corn (*Zea mays* L.) was investigated in a three-year study. Plots were infested with larvae when corn was in the 7-leaf stage of development. Most stalk borer tunnels began in the lower six internodes of the plant, and only 2.1% began above internode eight. Of the total number of internodes tunneled by stalk borer, 94.3% were located in internodes one through nine. The distribution of stalk borer tunnels showed little overlap with the distribution of European corn borer (*Ostrinia nubilalis* (Hübner)) tunnels. Measurements of stalk borer tunnels indicated that tunnel length continued to increase five weeks after plants were infested. A consumption model for stalk borer was derived from information on larval recovery and change in average tunnel length over time. A fifth-instar stalk borer that survives to pupation would be expected to produce a tunnel 15.8 cm long and consume 6.1 cm^3 of stalk tissue. Measurements of the lower 12 internodes indicated that tunneling shortened internodes at and above the tunnel. Although tunneled plants yielded significantly less grain than uninjured plants, yield loss varied by year.

INTRODUCTION

The stalk borer, Papaipema nebris (Guenée), can be a serious pest of corn, Zea mays L., especially in fields where terracing and no-till farming are employed for soil conservation (Lasack and Pedigo 1986, Stinner et al. 1984). Moths oviposit on grasses during the fall, and eggs hatch the following spring (Decker 1931). Typically, movement of stalk borers from grassy areas to corn is a function of temperature (Lasack and Pedigo 1986). In no-till situations, however, early movement may be induced if herbicides kill the grass host.

The extent of the yield loss from stalk borer injury is strongly influenced by the age of the corn at the time of attack (Levine et al. 1984, Section II). The research reported in this paper is part of a larger study that examined the impact of plant age at the time of stalk borer infestation on subsequent growth and yield of corn. During early vegetative stages, stalk borer larvae injure plants by feeding in the whorl and, ultimately, they may cut off the center whorl leaves or damage the growing point (see Section III). In plants that are at the 7-leaf stage and older, injury from stalk borer tends to be restricted to tunneling in the stalk below the growing point. In this paper, we characterize stalk borer tunneling in corn attacked at the 7-leaf stage of development and investigate the impact of tunneling on internode elongation and grain yield.

MATERIALS AND METHODS

Experimental Design

Research was conducted from 1986 to 1988 at the Johnson Research Farm located near Ames, Iowa. The experiment was designed as a split plot using four blocks each year. Hybrids were assigned to whole plots, and combinations of infestation level and sampling date were assigned to split plots. Two full-season hybrids were evaluated, Pioneer hybrids 3541 and 3377. Both hybrids were planted at a rate of 64,467 seeds ha^{-1} in 76.2-cm rows on 5 May 1986, 30 April 1987, and 3 May 1988. Either eight (1986, 1987) or two split plots (1988) were established in each hybrid strip. Each split plot consisted of ten corn plants within a row that were surrounded by a metal barrier. When plants were in the 7-leaf stage (Ritchie et al. 1986), half of the plots were infested with ten fifth-instar stalk borers obtained from a laboratory colony. The remaining plots were designated as uninfested check plots.

In 1986 and 1987, all plants within an infested plot and a check plot within each whole plot were harvested at 1, 3, or 5 weeks after infestion and at maturity. In 1988, plots were harvested at full maturity only. On each sampling date, plants within designated plots were individually tagged, cut off below ground level so as to retain all nodes, and returned to the laboratory for evaluation. In the laboratory, plants were split in half lengthwise, and data on number of stalk borers, tunnel location, tunnel length, internode length, grain yield, and grain moisture were recorded. Grain yield subsequently was adjusted to 15.5% moisture. Location and length of tunnels from a natural infestation of second-generation European corn borer, Ostrinia nubilalis (Hübner) also were recorded.

Data Analysis

Because not all plants within infested plots were injured by stalk borer, plot means were calculated for uninjured and injured plants within each plot and were used to evaluate the effect of stalk borer on internode elongation, tunnel length, and yield. Data were analyzed by using general linear model procedures in SAS (SAS Institute 1985). Comparisons of means were made by using orthogonal contrasts. To evaluate change in tunnel length over time, tunneled plants were assigned to one of three classes of tunnel length: (1) 0.1 to 4.0 cm, (2) 4.1 to 8.0 cm, and (3) longer than 8.0 cm. To test whether the percentage of tunnels within each class was affected by hybrids or time, the combined data set for 1986 and 1987 was analyzed by using the MANOVA option in PROC ANOVA (SAS Institute 1985). Wilks criterion (Rao 1973) was used to calculate the F statistic for this evaluation.

RESULTS AND DISCUSSION

Tunnel Distribution

Decker (1931) observed that stalk borers usually extend their tunnels upward in the stalk. Although entrance and exit holes were not recorded in our study, the lowest internode tunneled can be used as an indicator of the point of attack. The majority of stalk borer tunnels (79.5%) began in the lowest 6 internodes of the plant, and only 2.1% began above internode 8. Stalk borer larvae tend to restrict tunneling to the lower half of the stalk in plants attacked at the 7-leaf stage (Fig. 1). Of the total number of internodes tunneled by stalk borers, 94.3% were located in internodes 1 through 9. Typically, a single tunnel extended across several internodes. The number of internodes tunneled in samples taken on the final harvest date averaged 2.34 ± 0.12 in the three-year study. However, 10.3% of the tunneled plants had tunnels that extended across more than 5 internodes.

Calvin et al. (1988) reported that, in contrast to the stalk borer, the highest incidence of tunnels from the European corn borer occurred in internodes near the ear, and less than 6% of the tunnels were located below node 9. Although evaluations were restricted to the lower 12 internodes, the distribution of European corn borer tunnels closely followed that reported by Calvin et al. (1988) (Fig. 1). The presence of the stalk borer seemingly does not alter the distribution of European corn borer. The distribution of European corn borer tunnels in plots infested with stalk borer was not significantly different from that observed in uninfested check plots ($\underline{X}^2 = 11.1$, df = 6, $\underline{P} = 0.09$).

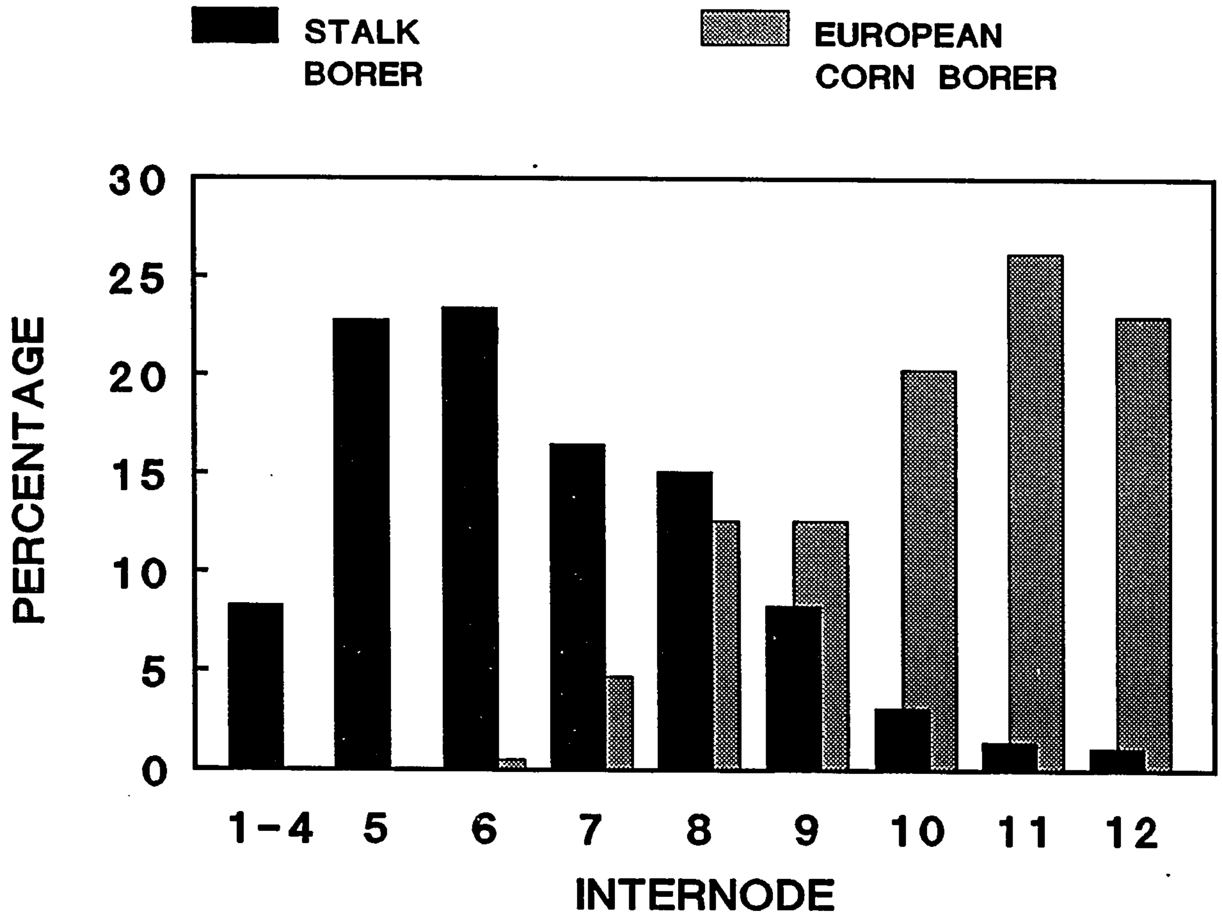


Figure 1. Distribution of stalk borer and European corn borer tunnels in the lower 12 internodes of corn (1986-1988, final harvest)

The spatial separation of these two species may serve to minimize contact between individuals and to lessen competition for food.

Length of Tunnels

In general, the average length of stalk borer tunnels increased steadily throughout the sampling period. Although the average tunnel lengths for each hybrid were not significantly different during either year (F < 0.05; df = 1, 3; P > 0.84), a significant hybrid-by-week interaction was detected during 1986 (F = 9.25; df = 3, 18; P = 0.0002). Orthogonal contrasts indicated that unusually short tunnels for Pioneer hybrid 3377 at final harvest in 1986 accounted for most of this difference (F = 31.6; df = 1, 18; P < 0.0001).

Parallel profile analysis (Johnson and Wichern 1982) was used to test if the proportion of tunnels in each class within a plot remained constant over time. A significant shift was detected in the distribution of tunnel lengths over time (Wilks criterion, F approximation = 2.31; df = 6, 86; P = 0.041). After one week, the majority of tunnels (81%) were less than 4 cm, and no tunnels were longer than 8 cm. For the rest of the sampling dates, the proportion of tunnels less than 4 cm remained relatively constant and ranged from 53 to 59%. The increase over time in the average length of tunnels primarily was a result of an increase in the proportion of tunnels more than 8 cm in length.

Tunnel elongation is a function of stalk borer survival. Although ten larvae were introduced into each plot, the number of plants tunneled by stalk borers averaged 6.31 ± 0.22 during 1986 and 1987. At 1, 3, and

5 weeks after infesting the plots, an average of 3.75 ± 0.34, 1.88 ± 0.34, and 1.44 ± 0.34 stalk borers per plot were recovered, respectively.

Information on stalk borer recovery was combined with data on tunneling activity to derive a consumption model for stalk borer that initially tunnel in 7-leaf corn. Because the number of tunneled plants did not change significantly over time ($F = 0.77$; df = 3, 42; $P = 0.52$) and a single stalk borer usually attacks each corn plant (Decker 1931, Lasack and Pedigo 1986), we assumed that the number of larvae per plot that initially fed on a plant was equal to the average number of injured plants per plot. Consequently, a single fifth instar that survives to pupation would be expected to produce a tunnel 15.8 cm long and consume 6.1 cm^3 of stalk tissue (Table 1).

Internode Elongation

To evaluate the effect of tunneling on internode elongation, comparisons were made between tunneled and uninjured plants for the total length of internodes 1 through 6, 7 through 9, and 10 through 12. Internode lengths of uninjured plants in check plots and infested plots were not significantly different (t tests, $P > 0.05$). However, tunneling by stalk borer had a significant impact on internode elongation (Fig. 2). Analysis of the combined data set for all years indicated that lengths of all internode groups for tunneled plants were significantly shorter than those of uninjured plants within infested plots ($F > 12.82$; df = 1, 19; $P \leq 0.002$). Although the majority of tunneled internodes were located below node 10, elongation of internodes

Table 1. Expected consumption of stalk tissue by fifth-instar stalk borers

Sample date	Larvae per plot[a]	Tunnel length per plant (cm)	Tunnel length per plot (cm)	Change in length per plot (cm)[b]	Change in length per larva (cm)[c]	Consumption per larva (cm^3)[d]
0	6.31	0	-	-	-	-
1 week	3.75	2.36	14.89	14.89	2.36	0.92
3 weeks	1.88	4.52	28.52	13.63	3.63	1.41
5 weeks	1.44	5.41	34.14	5.62	2.99	1.16
Harvest	-	6.97[e]	43.98	9.84	6.83	2.65
Total tunnel length and consumption per borer					15.81	6.14

[a]Initial population equal to average number of tunneled plants; population during weeks 1, 3, and 5 equal to average number of larvae recovered in destructive samples.

[b]Mean of 6.31 tunneled plants per plot.

[c]Change in length per plot divided by number of larvae present at previous sampling date.

[d]Mean cross-sectional area = 0.388 cm^2 (unpublished data).

[e]Excluded data from Pioneer hybrid 3377 for 1986.

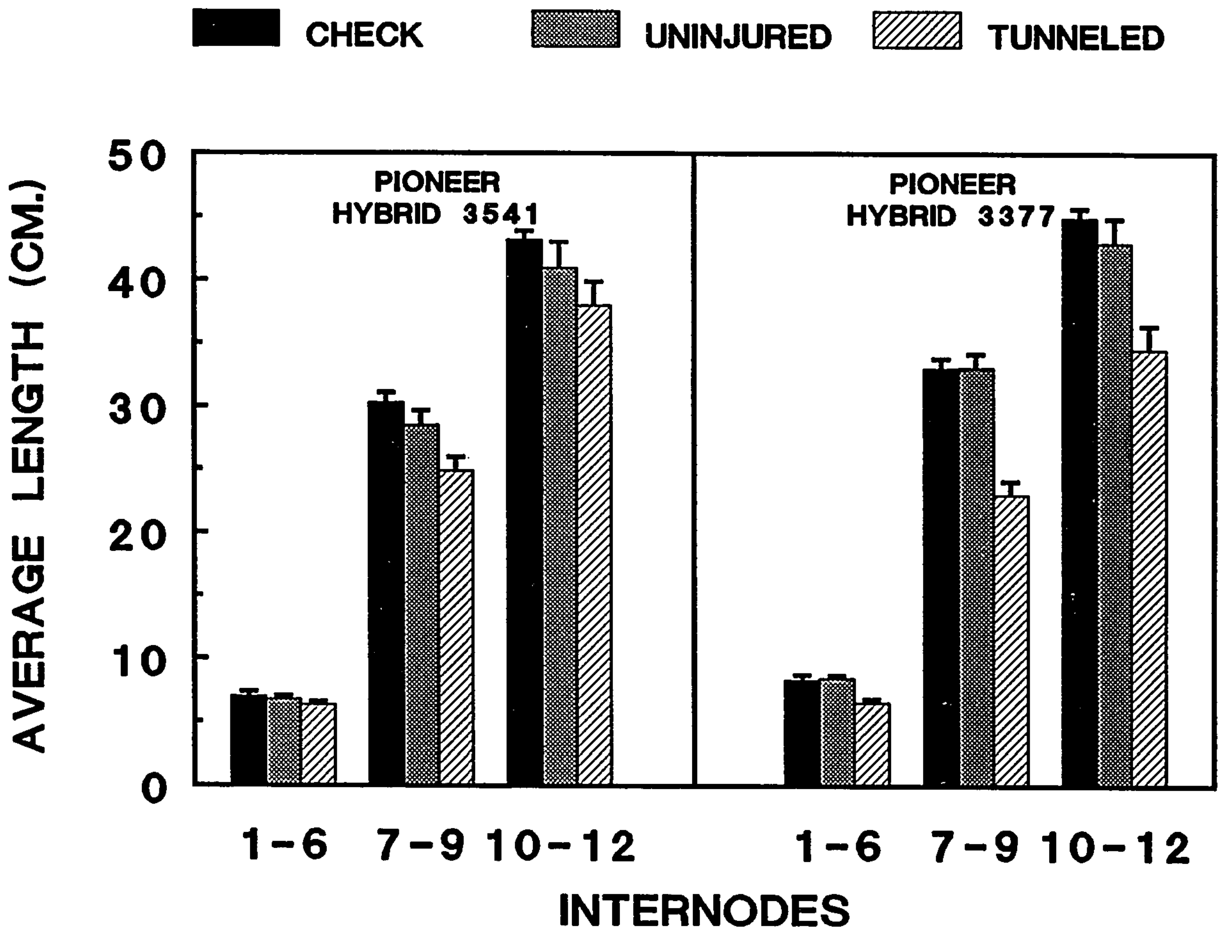


Figure 2. Average length of three internode groups for plants within check plots and infested plots in 1986-1988. Means for uninjured and tunneled plants within infested plots are reported. Bars indicate standard errors

10 through 12 also was affected. This internode group was an average of 5.7 cm shorter in tunneled plants than in uninjured plants. These data indicate that tunneling reduces internode elongation at and above the location of the tunnel.

In addition, tunneling in Pioneer hybrid 3377 had a greater impact on elongation of internode groups 1 through 6 and 7 through 9 compared with Pioneer hybrid 3541 (group 1-6: $F = 5.67$; df = 1, 19; $P = 0.028$; group 7-9: $F = 5.40$; df = 1, 19; $P = 0.031$).

Similarly, other stem-boring insects have been shown to alter stalk elongation. Chiang and Holdaway (1959) infested corn with European corn borer to coincide with first-brood attack. Internodes of late-planted corn showed a higher percentage reduction in length than early-planted corn. Williams and Davis (1984) also found that reduction in plant height was a function of the time corn was infested with southwestern corn borer (*Diatraea grandiosella* (Dyar)). At six weeks after planting, height of plants infested with southwestern corn borer was reduced by 10% compared with uninfested plants. However, infestations at eight weeks after planting showed little reduction in plant height.

Grain Yield

In stalk borer infested plots, tunneled plants yielded significantly less grain than uninjured plants for all years combined ($F = 8.99$; df = 1, 20; $P = 0.0071$). However, the extent of the yield reduction varied by year (Fig. 3). Yields of tunneled plants averaged 6.28, 46.5, and 43.9 grams per plant less than uninfested plants in infested plots during 1986, 1987, and 1988, respectively. This difference was significant only in 1988 ($F = 30.73$; df = 1, 6; $P = 0.0015$). In two of the three years, hybrids responded similarly to tunneling. However, a significant hybrid-by-tunneling interaction in 1988 indicated that Pioneer hybrid 3377 was less able to tolerate tunneling than Pioneer hybrid 3541 ($F = 12.84$; df = 1, 6; $P = 0.0116$).

One hypothesis for the yield reduction observed in plants tunneled by stalk borer is that flow of water and nutrients is disrupted. When moisture was limiting, as in 1988, the percentage reduction in grain yield attributed to stalk borer tunneling was greater than in years of adequate moisture. Tunneling also may alter subsequent growth and development. Chiang and Holdaway (1959) found that tunneling by European corn borer not only reduced internode lengths, but also reduced the size of the leaves. Further research on tunneling would be needed to elucidate the exact mechanism of yield loss.

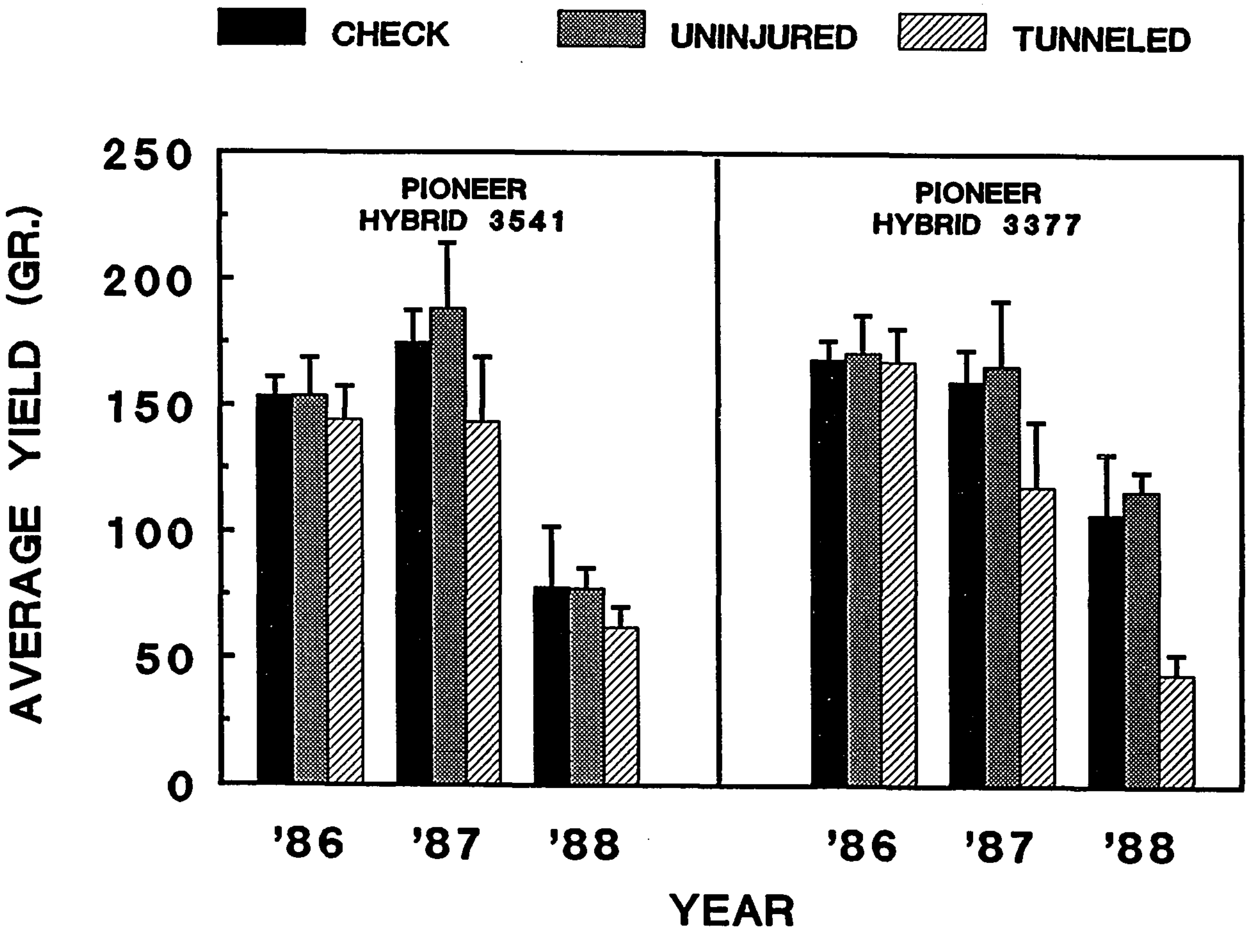


Figure 3. Yearly grain yield for plants within check plots and infested plots. Means for uninjured and tunneled plants within infested plots are reported. Bars indicate standard errors

SECTION II.

YIELD RESPONSE OF CORN STANDS TO STALK BORER (LEPIDOPTERA: NOCTUIDAE) INJURY IMPOSED DURING EARLY DEVELOPMENT

ABSTRACT

In a 3-year study, visual injury and grain yield were evaluated for two full-season corn (Zea mays L.) hybrids infested by stalk borer larvae, Papaipema nebris (Guenée), at leaf stages 1 through 7. Individual plants were assigned a rating based upon a six-class scale, and the average rating per plot was determined; 80% of the total number of injured plants within each plot were classified as injured within 1 week after infestation. A significant linear relationship between leaf stage and injury rating was detected in all years of the study, with injury rating declining at an average rate of 0.332 $\pm$ 0.033 points per leaf stage. In all years, infested plots yielded significantly less grain than uninfested check plots. Average yields of Pioneer hybrids 3541 and 3377 were reduced by 24.8% and 18.9%, respectively, when compared with uninfested check plots. In 2 of 3 years, yield losses declined linearly as plants were attacked later in development. However, in a drought-stressed year, leaf stage was independent of plot yield even though injury ratings for each leaf stage were very similar to those recorded during normal-rainfall years. Linear models, which regressed injury rating on yield, were developed and compared for each year and hybrid combination.

INTRODUCTION

During a growing season, corn plants (Zea mays L.) are stressed by injuries from a variety of pests that will ultimately reduce productivity. One of these pests, the stalk borer, Papaipema nebris (Guenée) may cause significant damage to seedling corn in reduced-tillage systems. Young larvae move from grassy areas, such as terraces, field edges, or patches of grass within a field, and search out a new host plant such as corn (Decker 1931, Lasack and Pedigo 1986). Visual symptoms of stalk borer attack include leaf feeding, whorl death or "dead heart", and tunneling in the stalk. If the plant survives the attack, it may send out new shoots or tillers.

In recent years, several investigators have evaluated the effect of stalk borer injury on grain yield of individual plants. Levine et al. (1984) examined yields of plants injured by natural infestations of larvae and found a tendency for plants attacked earlier in development to produce fewer harvestable ears and less grain than plants attacked later in the season. However, because natural infestations were used, many extraneous variables such as plant population, hybrid, infestation level, and leaf stage attacked could not be controlled, and actual yield loss was difficult to quantify. In another study, Bailey and Pedigo (1986) infested two- to four-leaf plants and compared yields of plants that were classified as uninfested, leaf feeding, or dead heart. Because stalk borer may attack more than one plant, plants also were classified as primary and secondary infestations. Although yields of plants with leaf feeding were not significantly different from yields of uninfested plants, the average yield of dead-hearted plants was reduced by 58.7% and 74.0% in primary and secondary infestations, respectively.

Direct yield losses caused by stalk borer feeding may be sustained through reduction in plant population and increases in weakened and barren plants (Levine et al. 1984, Bailey and Pedigo 1986). However, further quantification of the yield response of corn stands relative to the time and severity of stalk borer attack is critical to the development of decision rules and pest management strategies. To fill this void, this study used an experimental approach to evaluate the impact of leaf stage on visual injury and grain yield of two full-season corn hybrids infested by stalk borer larvae. An additional objective was to develop a method of predicting grain yield for corn infested with stalk borer.

MATERIALS AND METHODS

Experimental Design

The response of two corn hybrids to stalk borer injury was evaluated near Ames, Iowa, during 1986, 1987, and 1988. All larvae used in the study were reared from eggs collected the previous fall. During each year, eggs were stored outdoors until March, and then maintained at 5°C. Approximately 5 weeks before infesting plots, eggs were allowed to develop at room temperature (22.2°C). After hatching, individual larvae were placed in plastic cups (29.6 or 59.1 ml) and fed a black cutworm diet (Reese et al. 1972) as modified by Hendrix et al. (1990). If needed, fifth instars were synchronized for release by placing the larvae in a 10°C constant-temperature chamber (photoperiod of 14:10 (L:D)) for a period not exceeding 10 days.

Each test was conducted under minimum-tillage conditions consisting of a single pass with a disk before planting (1986 and 1987) or fall-chiseled and a single pass with a disk before planting (1988). Plots were arranged in a split-plot design with four replications. Whole plots consisted of two long-season hybrids, Pioneer hybrid 3541 and Pioneer hybrid 3377. Hybrids were planted on 5 May 1986, 30 April 1987, and 3 May 1988 in 4-row (1986, 1988) or 8-row (1987) strips that were 75 m long. The row spacing was 76.2 cm, and stands were seeded at a rate of 64,467 seeds/ha (26,100 seeds/ha). Terbufos (1986, 1988) and carbofuran (1987) were applied at labeled rates in the furrow at planting to suppress corn rootworm populations. Efficacy trials have shown that a planting-time application of a rootworm insecticide, such as carbofuran, does not reduce the observed injury from stalk borer when compared with control plots (Bailey et al. 1985b).

After corn emergence, subplots were established within each hybrid strip. Each subplot consisted of 10 consecutive corn plants surrounded by a 10.2-cm-tall aluminum barrier. In natural infestations, typically a single larvae attacks each corn plant (Lasack and Pedigo 1986, Decker 1931). To establish moderate stalk borer densities, subplots were infested with 10 4th- to 6th-instar stalk borers when corn had reached a given stage of development. One plot per hybrid per block was designated as uninfested check plot. In 1986, one subplot per strip was infested at the one-leaf, four-leaf, and seven-leaf stages of development (Ritchie et al. 1986), but in 1987 and 1988, the first seven leaf stages were infested. All subplots were hand-harvested at maturity, and yields were adjusted to 15.5% moisture.

Stalk Borer Survival

In 1986 and 1987, an additional 9 subplots per hybrid strip were established. These subplots were infested at the one-, four-, or seven-leaf stage and were used to monitor stalk borer survival at 1 week, 3 weeks, and 5 weeks after infestation. On the designated sampling date, plants were cut off at ground level and returned to the laboratory for dissection. The total number of stalk borers recovered was recorded for each subplot.

Visual Damage Rating

Individual plants within all plots were visually inspected twice a week from infestation through silking for stalk borer feeding. At the end of this period, individual plants were assigned a rating according to a six-point scale: (1) plant uninfested or minor leaf feeding present; (2) plant tunneled, very little leaf feeding, and growing point is not injured; (3) heavy leaf feeding; (4) dead heart, growing point not injured; (5) dead heart and plant tillers; (6) plant killed. The average injury rating and the number of injured plants within each subplot were recorded on each inspection date.

Data Analysis

Treatment differences were assessed by using analysis of variance procedures (SAS Institute 1985). Means were compared using orthogonal linear contrasts (Snedecor and Cochran 1980). Finally, the GLM procedure in SAS was used to develop regression models.

RESULTS AND DISCUSSION

Visual Damage

Visual signs of stalk borer feeding, such as heavy leaf feeding, wilting, or tunnels at the base of stalk, were not immediately detected after infestation of the plots. Typically, 80% of the total number of damaged plants within a plot were classified as injured within a week after introduction of larvae (Fig. 4). Some plants continued to be injured for up to 32 days after infestation. This extended period of attack is not unexpected because previous researchers reported that 32% of stalk borer larvae may infest a second plant after initial feeding on two- to four-leaf corn (Bailey and Pedigo 1986). Although the average number of days required for 95% of the total number of damaged plants to exhibit visual feeding was not dependent upon leaf stage in 1986 (F = 0.09; df = 1, 36; P = 0.92), young plants in 1987 and 1988 tended to be attacked over a much longer period than older plants (1987: F = 13.36; df = 1,36; P = 0.005; 1988: F = 4.10; df = 1, 34; P = 0.05). The higher incidence of plant mortality and severe injury in plots infested at early growth stages may have caused larvae to seek another host.

Comparison of Injury Levels

In all years, the average number of plants injured by stalk borer within a plot did not differ between hybrids, and no leaf stage by hybrid interactions were detected (F tests, P > 0.10). Although all plots were infested at a rate of 1 larva per plant, the number of plants with significant feeding (injury rating > 2) differed slightly between

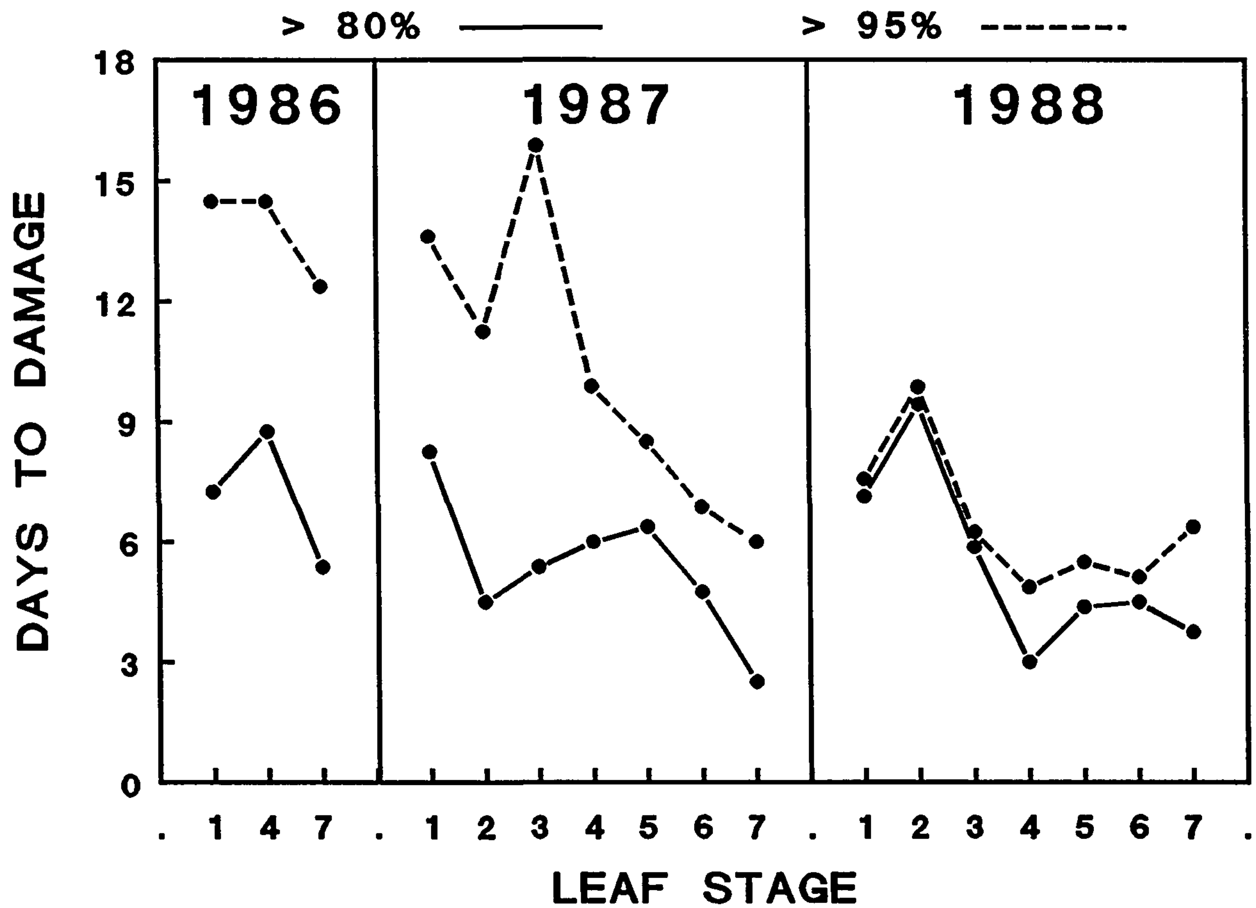


Figure 4. Number of days required for 80% and 95% of injured plants within a plot to show symptoms of stalk borer attack

years and between leaf stages (Fig. 5). Infested plots averaged 7.92 ± 0.32, 6.41 ± 0.21, and 5.54 ± 0.23 injured plants per plot in 1986, 1987, and 1988, respectively. However, the impact of leaf stage on injury level was not consistent across years. In 1986, no significant differences in injury level between leaf stages were detected ($\underline{F} = 2.19$; df = 2, 18; $\underline{P} > 0.10$). In contrast, a significant linear trend was indicated in 1987 ($\underline{F} = 4.99$; df = 1,42; $\underline{P} = 0.035$). When mean number of injured plants was regressed on leaf stage, injury rate was found to decline an average of 0.24 ± 0.12 plants for each additional leaf stage.

The major source of variation between leaf stages for injury rating in 1988 can be attributed to a very low frequency of injury in plots infested at leaf stages one and two. The number of injured plants in these plots averaged 2.88 ± 0.43. Stalk borer larvae used to infest these plots had been reared at 10°C for 7 to 10 days before being placed in plots. Once introduced into plots, many larvae were observed to be restless and did not feed on the corn. Larvae used in later infestations either were not cooled or were allowed to warm up in the laboratory for at least 1 day before being introduced into plots. The injury rates in the remaining plots were comparable to those rates observed in 1987 and averaged 6.60 ± 0.27 plants/plot. No significant differences between plots infested at leaf stages three through seven were detected ($\underline{F} = 0.83$; df = 4, 42; $\underline{P} = 0.51$).

Average Injury Ratings

In all years, the average injury ratings for Pioneer hybrids 3377 and 3541 did not differ significantly ($\underline{F}$ tests; $\underline{P} > 0.20$). Although the

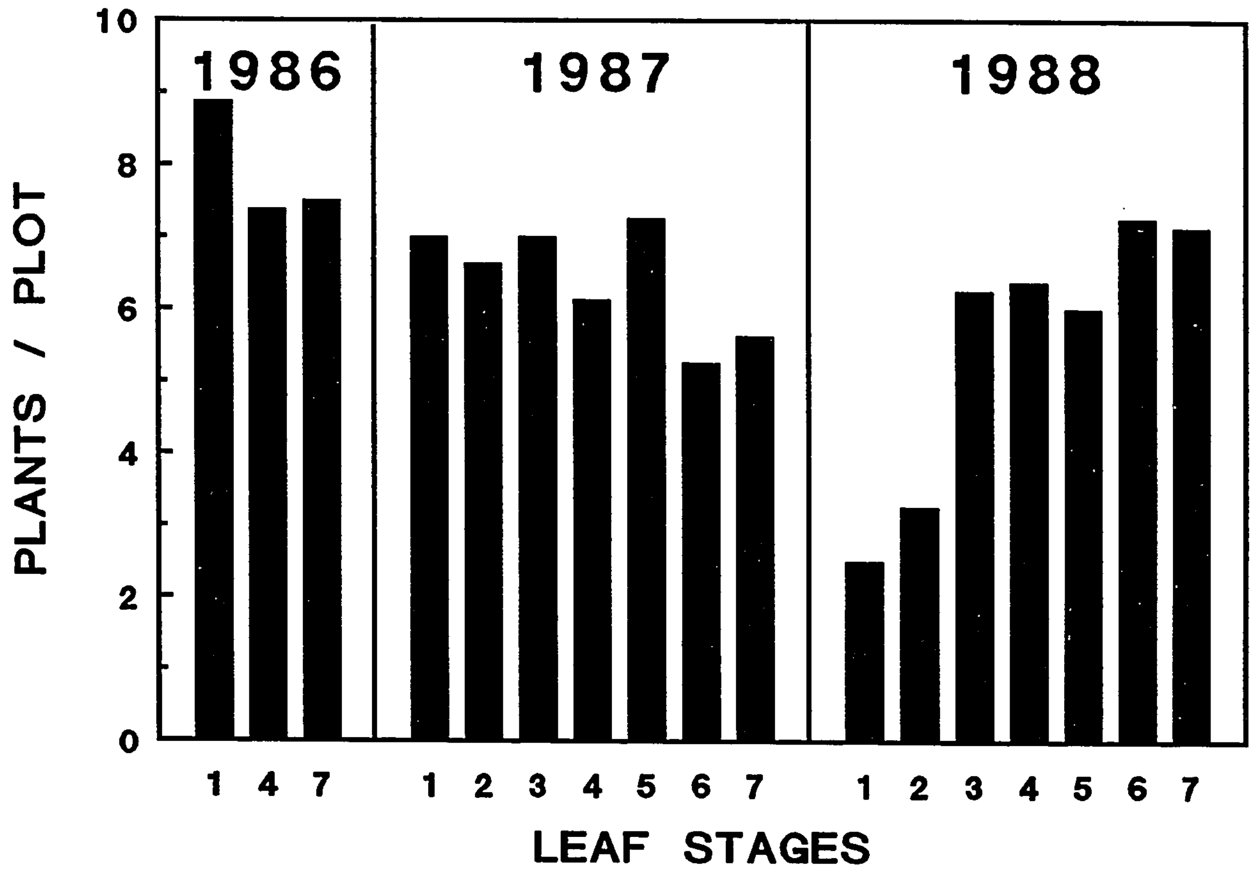


Figure 5. Average number of plants per plot that received an injury rating of 2 or higher

number of plants attacked by stalk borer was not consistently related to leaf stage, a strong linear relationship between leaf stage and injury rating was found in 1986 (F = 116.9; df = 1, 18; P = 0.0001) and 1987 (F = 56.1; df = 1, 42; P = 0.0001). In 1988, the average injury rating was significantly lower in one- and two-leaf plots than in the remaining infested plots (F = 16.87; df = 1, 42; P = 0.0001). The lower number of plants injured in the one- and two-leaf plots probably contributed to the low injury rating. However, as in the 1986 and 1987 trials, leaf stage was linearly related to injury rating for plots infested at leaf stages three through seven (F = 17.44; df= 1, 42; P = 0.0001).

Overall, severity of injury, as defined by average injury rating, declined as plants grew older. When means are calculated by leaf stage and year and the one- and two-leaf plots for 1988 are excluded, the relationship between leaf stage (X) and injury rating (Y) has an R^2 of 0.88. The equation (with standard errors) is:

$$Y = 4.31 - 0.332(X)$$
$$(0.26) \quad (0.033)$$

This relationship would hold when 50-80% of the plants in an area are injured by stalk borer.

Stalk Borer Survival

One factor that potentially could contribute to observed differences in infestation level and damage rating was stalk borer survival. Data collected during 1986 and 1987 indicated that choice of hybrid had little impact on the number of larvae recovered (F tests; P >

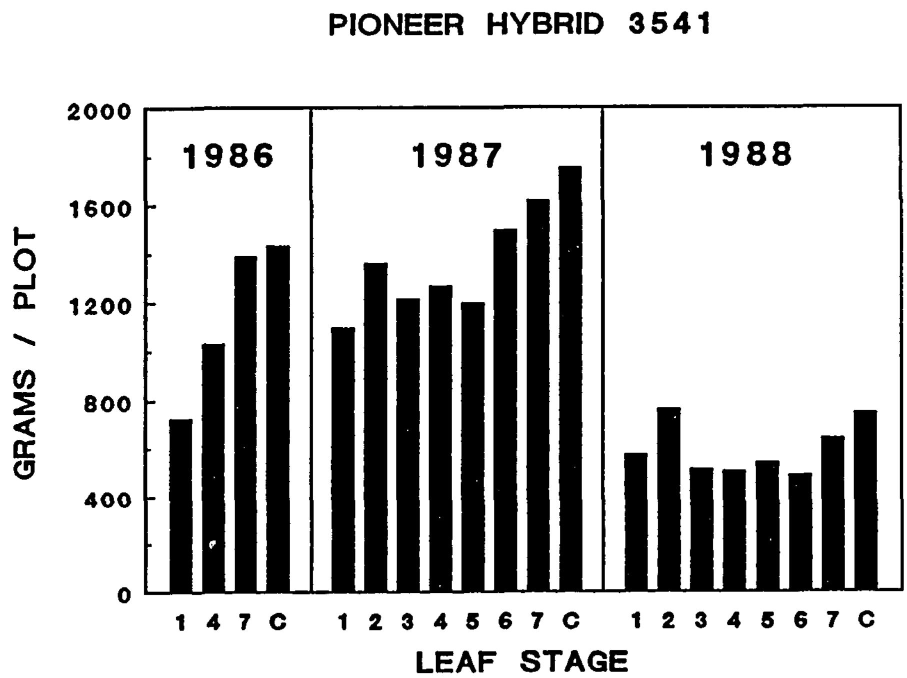
0.49). However, stalk borer survival rates were not the same for all sample dates and leaf stages. The most dramatic decrease in survival occurred within the first week after infestation when stalk borer numbers declined from an initial 10 larvae per plot to averages of 4.33 $\pm$ 0.28 and 3.50 $\pm$ 0.28 larvae per plot in 1986 and 1987, respectively. By 5 weeks after infestation, the number of stalk borers recovered had declined to 1.13 $\pm$ 0.28 and 1.00 $\pm$ 0.30 larvae per plot in 1986 and 1987, respectively. Orthogonal contrasts indicated a significant linear effect of date during both years ($F > 40.1$; df = 1, 48; $P < 0.0001$) and a significant quadratic effect in 1986 ($F = 8.09$; df = 1, 48; $P =$ 0.0065). This fairly rapid decline in stalk borer numbers over time is comparable to observations from natural stalk borer infestations. In a previous study, we found that natural larval populations in corn declined by 65% within 5 weeks after the population peak (Lasack and Pedigo 1986). Because stalk borer movement into corn occurred over a period of several weeks, actual mortality may have been higher.

Although the number of recaptured larvae in plots infested at the three leaf stages differed significantly, the effect was not consistent across years. In 1986, recovery of stalk borer after 1 week declined as plants were infested later in development. However, the reverse was true in 1987. In addition, the relationship between the number of stalk borers recovered and the number of plants injured was inconsistent, being positively correlated in 1986 and negatively correlated in 1987. Because all plots were planted on the same date and infestation occurred on different dates (to coincide with the appropriate leaf stage), leaf stage was confounded with environmental factors including rainfall, temperature, natural enemy populations, and the physical condition of larval cohorts used to infest the plots. These uncontrolled factors may have influenced stalk borer survival and masked any real leaf stage effect.

Yield Response

The pronounced differences in average plot yields between years primarily was caused by variations in weather patterns (Fig. 6). Rainfall totals during the months of May, June, and July totaled 41.45 cm in 1986 and 28.63 cm in 1987. In sharp contrast, 1988 was characterized by drought conditions when rainfall for the same 3 months totaled 14.53 cm. Plants were stunted and overall yield was reduced by 30-50% compared with the previous 2 years. These conditions provided a unique opportunity to compare and contrast the effect of stalk borer injury under near normal rainfall (1986, 1987) and under drought conditions (1988).

The two hybrids used in this study are considered to be full-season hybrids for central Iowa and require 2680 growing degree units (base 50°F) to reach black layer (Ritchie et al. 1986). Pioneer hybrid 3541 is not considered to be very stress tolerant and performs best under medium to high planting rates (59,300 to 66,700 kernels per hectare). On the other hand, Pioneer hybrid 3377 has excellent stress tolerance and low population requirements. Recommended planting rates range from 54,340 to 61,750 kernels per hectare. In all years of this study, the overall average grain yield was higher for Pioneer hybrid 3377 than for Pioneer hybrid 3541. However, this difference was



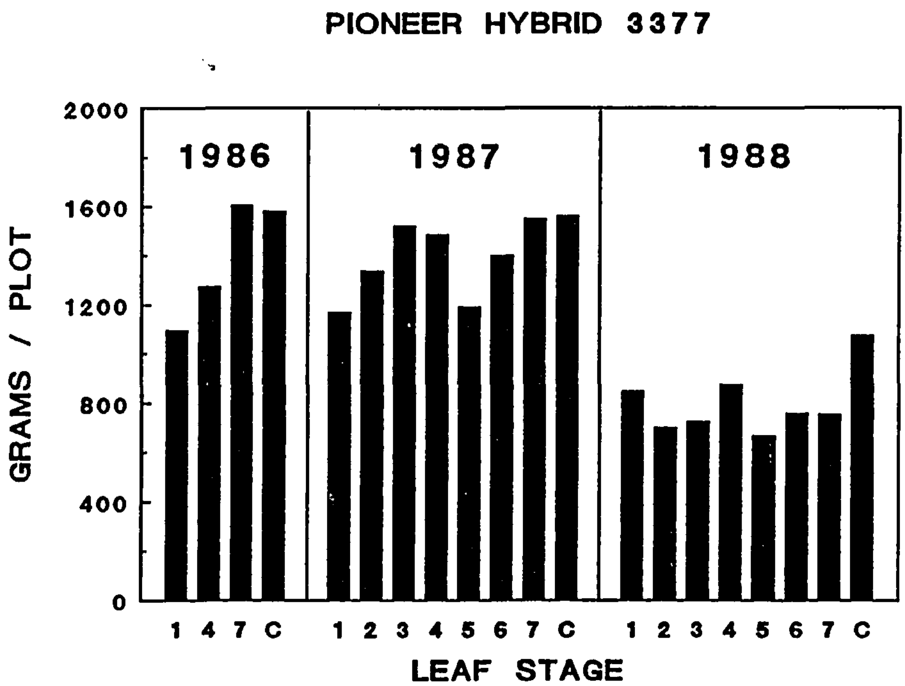


Figure 6. Average grain yield for each hybrid, leaf stage at time of infestation, and year combination. Uninfested check plots are indicated by the letter C

significant only in 1986 (F = 14.50; df = 1, 3; P = 0.03). Average yields for the 3-year period were 1145.0, 1376.2, and 607.0 g per plot for Pioneer hybrid 3541 and 1388.1, 1402.3, and 771.8 g per plot for Pioneer hybrid 3377.

As shown in Fig. 6, both hybrids showed a similar response pattern when infested at the various leaf stages, and no significant hybrid by leaf stage interaction was detected. In all years, infested plots yielded significantly less grain than uninfested check plots (linear contrasts, $F \geq 6.81$; $P < 0.014$). Over the 3-year period, average yields of infested plots were reduced by 24.8% and 18.9% for Pioneer hybrids 3541 and 3377, respectively, when compared with uninfested check plots. In 2 of 3 years, yield losses associated with stalk borer injury declined linearly as plants were attacked later in development (1986: F = 31.84; df = 1, 18; $P < 0.0001$; 1987: F = 5.63; df = 1, 42; P = 0.023). No significant quadratic effect was detected in any year. However, in a drought-stressed year, plot yield was independent of leaf stage (1988: F = 0.47; df = 6, 42; P = 0.827). This occurred despite injury ratings in plots infested at stages three through seven that declined with leaf stage at the same rate as in the previous two years.

Modeling Yield Loss Relationships

In developing a regression model to predict grain yield in corn infested by stalk borers, we first investigated the relationship between injury rating, number of plants attacked, leaf stage, and plot yield (Table 2). Grain yield was most strongly related to injury rating, followed by number of plants injured and leaf stage. The advantage of

Table 2. Correlations between variables and probability levels for plots infested with stalk borer larvae during each year of the study

Variable 1	Variable 2	1986	1987	1988
Plants injured	% Yield[a]	-0.509 (0.011)	-0.492 (0.0001)	-0.236 (0.080)
Rating	% Yield	-0.919 (0.0001)	-0.665 (0.0001)	-0.252 (0.061)
Leaf stage	% Yield	0.747 (0.0001)	0.273 (0.041)	-0.095 (0.487)
Plants injured	Rating	0.556 (0.0005)	0.753 (0.0001)	0.692 (0.0001)
Leaf stage	Rating	-0.875 (0.0001)	-0.688 (0.0001)	-0.090 (0.511)
Plants injured	Leaf stage	-0.297 (0.159)	-0.259 (0.054)	-0.636 (0.0001)

[a]Yield expressed as a percentage of the check plot yield.

using injury rating to model yield is that injury rating incorporates effects of both leaf stage and number of plants attacked.

Separate models were developed for each year and hybrid combination using data for all treatments. To adjust for year and hybrid effects, yield was expressed as a percentage of the corresponding check plot yield. In all years, a simple linear model best described the relationship between injury rating and percent yield for Pioneer hybrid 3541, whereas models that included a linear and quadratic term for rating were better predictors of yield for Pioneer hybrid 3377 in 1986 and 1987 (Table 3). The addition of number of plants injured or leaf stage did not significantly improve any of the models.

Under drought conditions, as present during 1988, injury rating was a poor predictor of final yield for either hybrid. Rather, final yield was more dependent upon the presence or absence of insect stress.

Table 3. Regression models to predict percent yield (%Y) as a function of injury rating (X). Standard errors for coefficients appear in parentheses below each model

Pioneer hybrid	Year	Regression equation	N	R^2
3541	1986	%Y = 121.6 - 14.7*X (4.2) (1.3)	16	0.897
	1987	%Y = 120.3 - 15.5*X (5.4) (1.9)	32	0.693
	1988	%Y = 100.4 - 8.9*X (16.2) (6.5)	32	0.058
	1986-1987	%Y = 120.2 - 15.2*X (3.6) (1.2)	48	0.769
3377	1986	%Y = 83.0 + 22.2*X - 6.6*X^2 (13.9) (11.6) (2.1)	16	0.824
	1987	%Y = 81.9 + 19.6*X - 5.5*X^2 (16.9) (12.6) (2.2)	32	0.445
	1988	%Y = 100.5 - 11.2*X (12.6) (5.1)	32	0.138
	1986-1987	%Y = 84.1 + 18.9*X - 5.6*X^2 (12.1) (9.3) (1.6)	48	0.540

In contrast, a direct relationship existed between rating and yield in years with more normal rainfall. This relationship was less variable for Pioneer hybrid 3541 than for Pioneer hybrid 3377. In addition, the models for the combined 1986-1987 data set predict that Pioneer hybrid 3377 can tolerate more injury than Pioneer hybrid 3541. Yield losses of 10 and 20% corresponded to injury ratings of 1.99 and 2.64 for Pioneer hybrid 3541 compared with injury ratings of 3.02 and 3.58 for Pioneer hybrid 3377.

Because of the inherent difficulty of successfully using an insecticide to treat stalk borer infested fields and the added pressure to reduce insecticide usage, alternative approaches for reducing losses to stalk borer are needed. Although further research is recommended, the results of this study suggest that hybrid selection may be an alternative in situations of low to moderate stalk borer pressure, as well as to reduce losses when used in conjunction with an insecticide.

SECTION III.

INJURY PROFILES AND YIELD RESPONSES OF SEEDLING CORN ATTACKED BY STALK BORER (LEPIDOPTERA: NOCTUIDAE)

ABSTRACT

The impact of feeding by the stalk borer, Papaipema nebris (Guenée), on the visible injury and grain yield of individual corn plants, infested at various developmental stages, was evaluated experimentally from 1986 to 1988. Injury profiles differed by growth stage, with younger plants having a higher incidence of severe injury (dead heart, tillering, plant death). Plants attacked at the 6-leaf stage or older were not as vulnerable to severe injury because tunneling occurred below the growing point. Grain yield, number of kernels per plant, and average kernel weight declined as the severity of injury increased. In 2 of 3 years, plants attacked earlier in development tended to yield more at the same injury rating than plants attacked later. In addition, uninfested plants in infested plots yielded more than uninfested plants in check plots. Plot yield losses seem to be moderated by the ability of uninfested or slightly injured plants to compensate for severe stalk borer injury. Regression models were developed to predict yield components for individual plants from injury rating and average rating of the plot.

INTRODUCTION

The stalk borer, Papaipema nebris (Guenée), is native to North America, and as a larva, feeds in the stems of many grasses and broadleaved plants. This polyphagous feeding habit has contributed to the species' role as an important, although sporadic, pest of many cultivated crops, including corn, wheat, and vegetables (Decker 1931). During the late 1800s and early 1900s, the stalk borer was mentioned as one of the principal insects of the year in the Yearbook of the Department of Agriculture from 1902 to 1908 and listed as one of the ten most destructive insects of the year in the 1927 Insect Pest survey (Decker 1931). With the advent of improved herbicides, combined with conventional tillage practices, stalk borer damage was limited to scattered corn plants bordering field edges and waterways. In recent years, however, the situation has reversed. The stalk borer has become a sporadic, but serious pest throughout the Midwest in conservation-tillage fields (Rubink and McCartney 1982).

Several researchers have investigated the yield loss associated with stalk borer injury. Bailey and Pedigo (1986) infested 2- to 4-leaf corn plants with larvae and found that significant yield loss occurred when the whorl of the plant was killed (dead heart). Leaf feeding, however, did not cause significant yield losses. In another study, Levine et al. (1984) observed that natural infestations of stalk borer caused greater yield losses in corn at earlier stages of development. However, they were not able to quantify the losses.

In an effort to model the relationship between injury and yield loss, we assessed the stand response to infestations of stalk borers that were introduced at various leaf stages (see Section II). Based on the results of that study, a regression model was developed that related average injury rating of the plot to yield. Our goal in this study was to understand how individual plants respond to stalk borer injury and to characterize the visible symptoms and yield-loss relationships when corn is infested at various growth stages.

MATERIALS AND METHODS

Experimental Design

A 3-year study was conducted near Ames, Iowa, to evaluate the response of seedling corn to stalk borer injury. Plots were established in a field that had been fall chiseled (1988) and/or disked once (1986-1988) before planting. Fertilizer was applied each year at a rate of 168-56-112 kg ha^{-1} (N-P-K). A preemergence application of metolachlor in combination with atrazine (1987) or cyanazine (1986, 1988) was used to suppress weeds. Terbufos (1986, 1988) and carbofuran (1987) were applied in-furrow at planting to suppress corn rootworm populations (*Diabrotica* spp.). Efficacy trials have shown that a planting-time application of a rootworm insecticide, such as carbofuran, does not reduce the observed injury from stalk borer when compared with control plots (Bailey et al. 1985b).

The experimental design was a split plot with four replications. Whole plots consisted of two hybrids, Pioneer hybrid 3541 and Pioneer hybrid 3377. Both hybrids are considered full-season hybrids for central Iowa and have high yield potential. Pioneer hybrid 3541 tends to be less stress tolerant than Pioneer hybrid 3377. Both were planted at a rate of 64,467 seeds ha^{-1} in 76.2-cm rows. Whole plots were four rows wide in 1986 and 1988 and eight rows wide in 1987. Hybrids were planted on 5 May 1986, 30 April 1987, and 3 May 1988.

Individual plots were established within each hybrid strip after corn emergence. Each split plot consisted of 10 adjacent plants surrounded by a 10.2-cm metal barrier. One plot in each hybrid strip was designated as an uninfested check, and the remaining three (1986) or seven (1987, 1988) plots were infested at the assigned corn developmental stage with stalk borer larvae. In 1986, plots were infested at 1-, 4-, and 7-leaf stages (Ritchie et al. 1986). In 1987 and 1988, plots were infested at each of the first seven growth stages. To achieve a moderately high infestation of stalk borer, 10 larvae per plot were placed at the base of plants and allowed to feed.

All larvae used in the study were reared from eggs collected the previous fall. Eggs were stored outdoors until March and then maintained at 5°C until needed. Approximately five weeks before each infestation date, groups of eggs were allowed to hatch. After hatching, individual larvae were placed in plastic cups (29.6 or 59.1 ml) and fed a modified black cutworm diet (Reese et al. 1972). Temperature was maintained at 22.2°C until larvae were fifth instars. If needed, fifth instars were synchronized for release by placing larvae in a 10°C constant-temperature chamber (photoperiod of 14:10 (L:D)) for a period not exceeding 10 days.

Data Collection

Individual plants were visually evaluated twice a week from emergence through silking. At the end of this period, each plant was assigned a rating based on a 6-point scale (see Section II). Plants were classed as (1) healthy, (2) tunneled only, (3) having leaf feeding exceeding 10%, (4) dead heart with main stem regrowing, (5) dead heart with plant tillering, and (6) killed. At maturity, ears from all plants within plots were individually harvested and returned to the laboratory.

Data collected included yield per plant, average kernel weight, and moisture. Grain yield for each plant was adjusted to 15.5% moisture. The average kernel weight was determined by weighing 40 randomly selected kernels per plant. The total number of kernels per plant was determined by dividing grain yield by average kernel weight.

Data Analysis

Because the number of plants injured per plot was not constant, the number of plants within injury classes 2 through 6 was expressed as a proportion of the total number of plants injured. To determine if hybrids or leaf stage influenced the proportion of the plants in each class, profile analysis, as described by Johnson and Wichern (1982), was done by using MANOVA procedures in SAS (SAS Institute 1985). Data from infested plots for all years of the study were included in this analysis.

Analysis of variance procedures in SAS were used to evaluate the impact of main effects (hybrid and leaf stage) and interactions on measured yield variables during each year of the study. In addition, variation among plants within plots was evaluated by separating out linear and quadratic components for rating and interactions with main effects. Finally, multiple regression models were developed with the REG procedure in SAS.

RESULTS AND DISCUSSION

Injury Profiles

Profiles for each leaf stage and hybrid combination are presented in Fig. 7. Parallel profile analysis for the combined 1986-1988 data set did not detect any significant differences in the injury profiles between hybrids ($F = 1.14$; $df = 4, 8$; $p = 0.40$) or any hybrid by leaf stage interactions ($F = 0.85$; $df = 24, 333$; $p = 0.67$). However, injury profiles for each leaf stage were not parallel ($F = 17.46$; $df = 24, 333$; $p = 0.0001$). In general, infestations of larvae in 1- and 2-leaf plots characteristically caused high plant mortality (rating = 6), whereas very little mortality occurred after the 3-leaf stage. Similarly, Bailey and Pedigo (1986) reported that plant mortality ranged from 0 to 3.1% for 2- to 4-leaf corn. In our study, a high proportion of dead-hearted plants survived attack at leaf stages 3 to 5 by regrowing the main stem (rating = 4) or producing tillers if the growing point was injured (rating = 5). After plants reached the 6-leaf stage, the incidence of severe injury declined sharply. Instead, a high percentage of plants only showed tunneling in the lower stalk (rating = 2).

The position of the growing point probably is one of the most important factors regulating the severity of injury. Beginning at leaf stage 6, the growing point is aboveground, and rapid elongation of the stalk begins (Ritchie et al. 1986). Previously, I reported that stalk borer larvae confined their tunneling to the lower third of the stalk and that most borers (79.5%) entered at internodes 6 or lower (see section I). Therefore, the majority of plants that are 6-leaf stage or

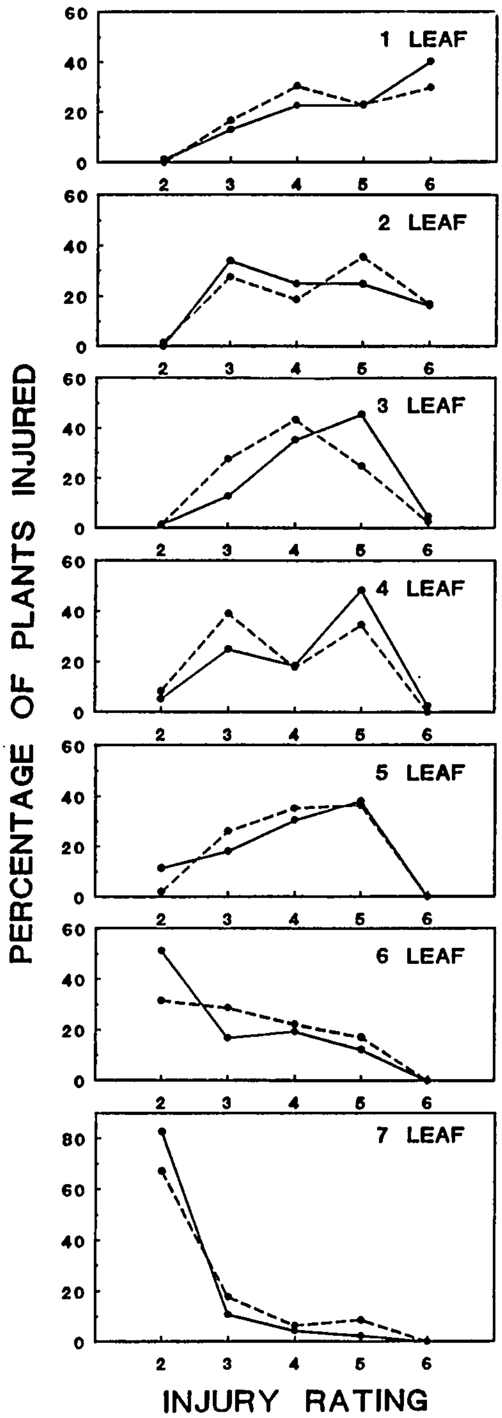


Figure 7. Average percentage of plants in injury classes 2-6 for each leaf stage and hybrid combination. Solid line, Pioneer hybrid 3541; dashed line, Pioneer hybrid 3377

older are not vulnerable to severe injury from stalk borer because tunneling occurs below the growing point.

Grain Production

The average yields of individual plants were strongly affected by injury rating (Fig. 8). Analysis of variance detected a significant linear relationship between rating and yield in all years (1986: $F = 261.1$, $df = 1, 271$, $p < 0.0001$; 1987: $F = 444.1$, $df = 1,547$, $p < 0.0001$; 1988: $F = 384.0$, $df = 1, 546$, $p < 0.0001$). In addition, a significant quadratic relationship also existed between rating and yield in 1986 and 1987 (1986: $F = 7.0$, $df = 1, 271$, $p = 0.0086$; 1987: $F = 37.80$, $df = 1, 546$, $p < 0.0001$).

In 1986 and 1987, there was a strong tendency for plants attacked early in development to yield more at the same injury rating than plants attacked later. Similarly, Bailey and Pedigo (1986) reported that in 2 of 3 years, dead-heart plants yielded nearly twice as much in primary infestations of 2- to 4-leaf corn compared with secondary infestations. In addition, we found that uninfested plants in infested plots (rating = 1) yielded as much as 47% more than plants in uninfested check plots (Table 4).

Several factors may contribute to this phenomenon. Competition between plants within a plot may be affected by infestation level and timing of injury. As previously noted, the frequency of severe injury was much greater in younger plants than in older plants. Consequently, the average rating of a plot declined as plants were infested later in development (see Section II). In plots infested with stalk borers,

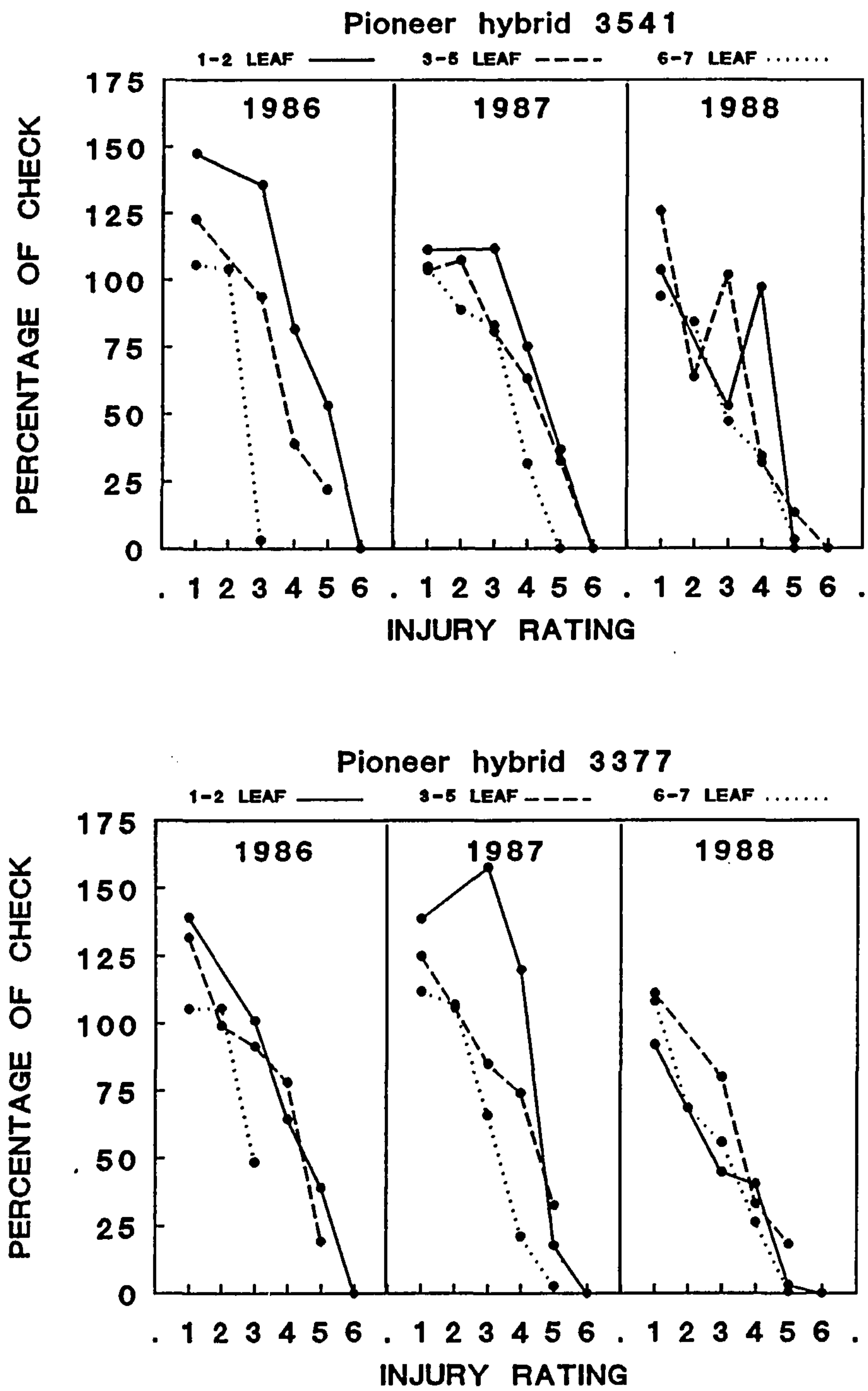


Figure 8. Grain yield per plant (expressed as a percentage of the check) for various combinations of leaf stage, injury rating, and hybrid

Table 4. Yield expressed as a percentage of the corresponding check plot average for uninjured plants in infested plots

Pioneer hybrid	Leaf stage	1986	1987	1988
3541	1-2	147.5*	111.2	103.7
3541	3-5	122.7	103.5	125.9*
3541	6-7	105.5	104.8	93.7
3377	1-2	139.1*	138.6*	91.9
3377	3-5	131.8*	124.9*	111.0
3377	6-7	105.3	111.8	108.0

*Significantly different from the check plot (t test, $p \leq 0.05$).

relatively healthy plants may be able to compete more effectively for requisites and respond by increasing grain production compared with plants in an uninfested stand. Considerable research on the effect of plant density on individual plant yield and stand yield has been conducted. Individual corn plants yield more grain per plant as plant density decreases (Duncan 1958). Thus, plot yield losses seem to be moderated by the ability of uninfested plants to compensate for severe stalk borer injury.

Although defoliation usually lowers yield, some workers have found little or no yield reduction in corn defoliated at very early or very late growth stages (Eldridge 1935, Hicks et al. 1977, Bailey and Pedigo 1986). One hypothesis, proposed by Crookston and Hicks (1978), is that early defoliation may stimulate yield in some hybrids. In 2 of 3 years of our study, average grain yields of defoliated plants (rating = 3), from plots infested at the 1- and 2-leaf stage, equalled or exceeded the average yield of plants from check plots. Defoliation may have stimulated grain yield, but this hypothesis does not explain why uninfested plants in the same plot also outyielded the check.

Finally, leaf feeding (rating = 3) or dead heart, where the growing point is not injured (rating = 4), removes much less of the potential leaf area of the plant when defoliation occurs early in development (unpublished data).

Drought Stress

We reported that overall yields in 1988 were reduced 30-50% compared with 1986 and 1987 as a result of drought stress (see Section II). When yield was expressed as a percentage of the check, uninfested plants of Pioneer hybrid 3377 did not compensate for stalk borer injury as in previous years. Although adjusted yields of Pioneer hybrid 3541 were more variable in 1988, the overall relationship to injury rating was not much different from that observed in 1987.

Kernel Number and Weight

Of the two components of grain yield, kernel number was more highly correlated with yield than was kernel weight (Table 5). Similar relationships between grain weight and grain number have been reported. Gallagher et al. (1975) observed that grain weight of cereal crops was more stable, and large differences in yield usually resulted from fluctuations in grain number. In 3-year averages of the two hybrids,

Table 5. Correlations[a] between measured variables for individual plants (1986-1988)

Variable	Grain yield	Number of kernels	Kernel weight	Injury rating
No. of kernels	0.937			
Kernel weight	0.763	0.675		
Injury rating	-0.525	-0.589	-0.474	
Plot rating	-0.174	-0.239	-0.192	0.618

[a] $N = 1600$, $p < 0.0001$.

increasing injury directly coincided with a decline in kernel number (Fig. 9) As with grain yield, the reduction in kernel number was greater for older plants than for younger plants at the same injury rating. In contrast, kernel weight tended to remain more stable (Fig. 10). Significant linear and quadratic relationships between injury rating and kernel weight were detected during each year of the study (linear: $F > 128$, $p < 0.0001$; quadratic: $F > 35.0$, $p < 0.0001$). For plants attacked at the 5-leaf stage or younger, little reduction in grain weight was detected unless the growing point was injured (rating = 5 or 6). Plants injured at the 6- and 7-leaf stages tended to have 20% lower grain weights at injury ratings 3-5 than younger plants.

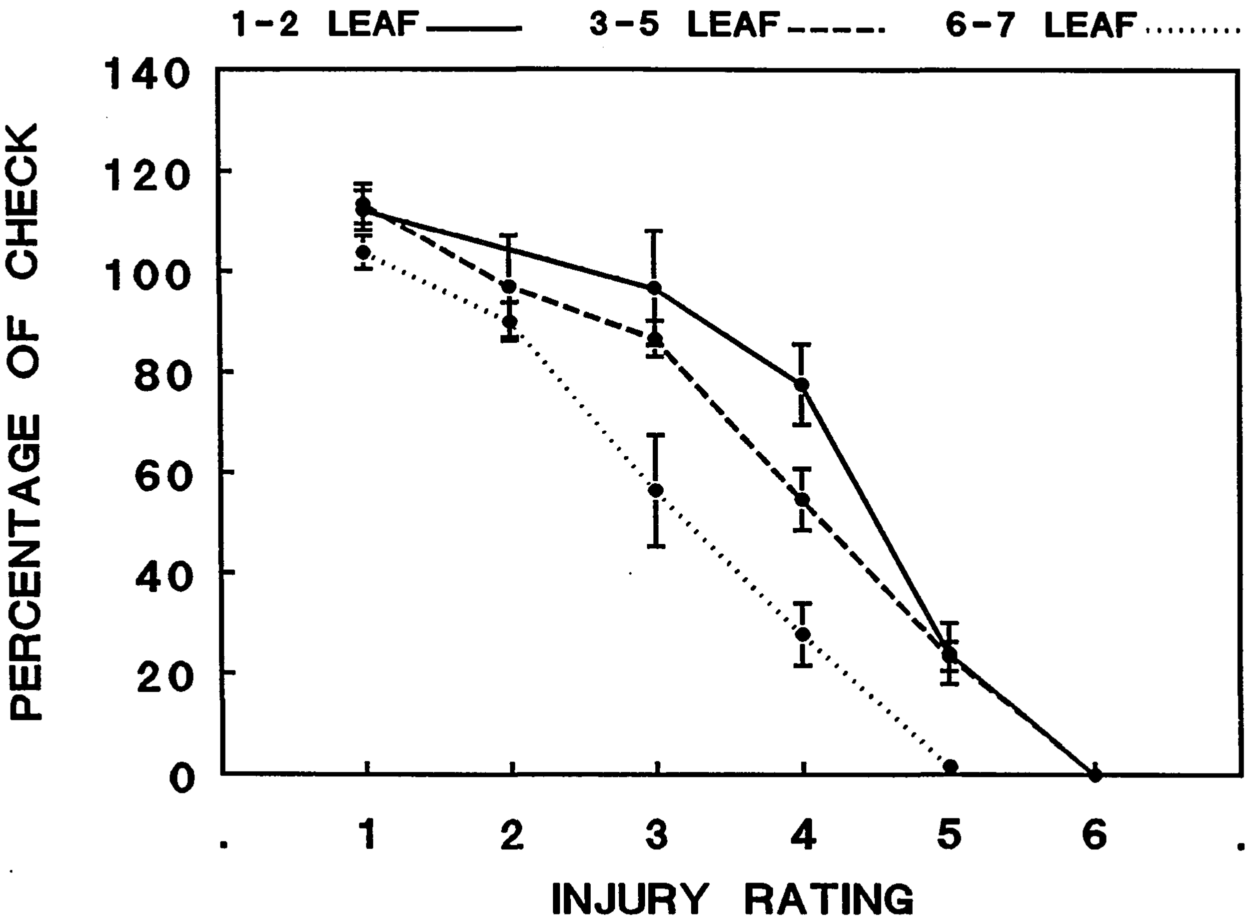


Figure 9. Average number of kernels per plant (expressed as a percentage of the check) for various combinations of leaf stage and injury rating. Standard error bars represent variability between years and hybrids (N = 6)

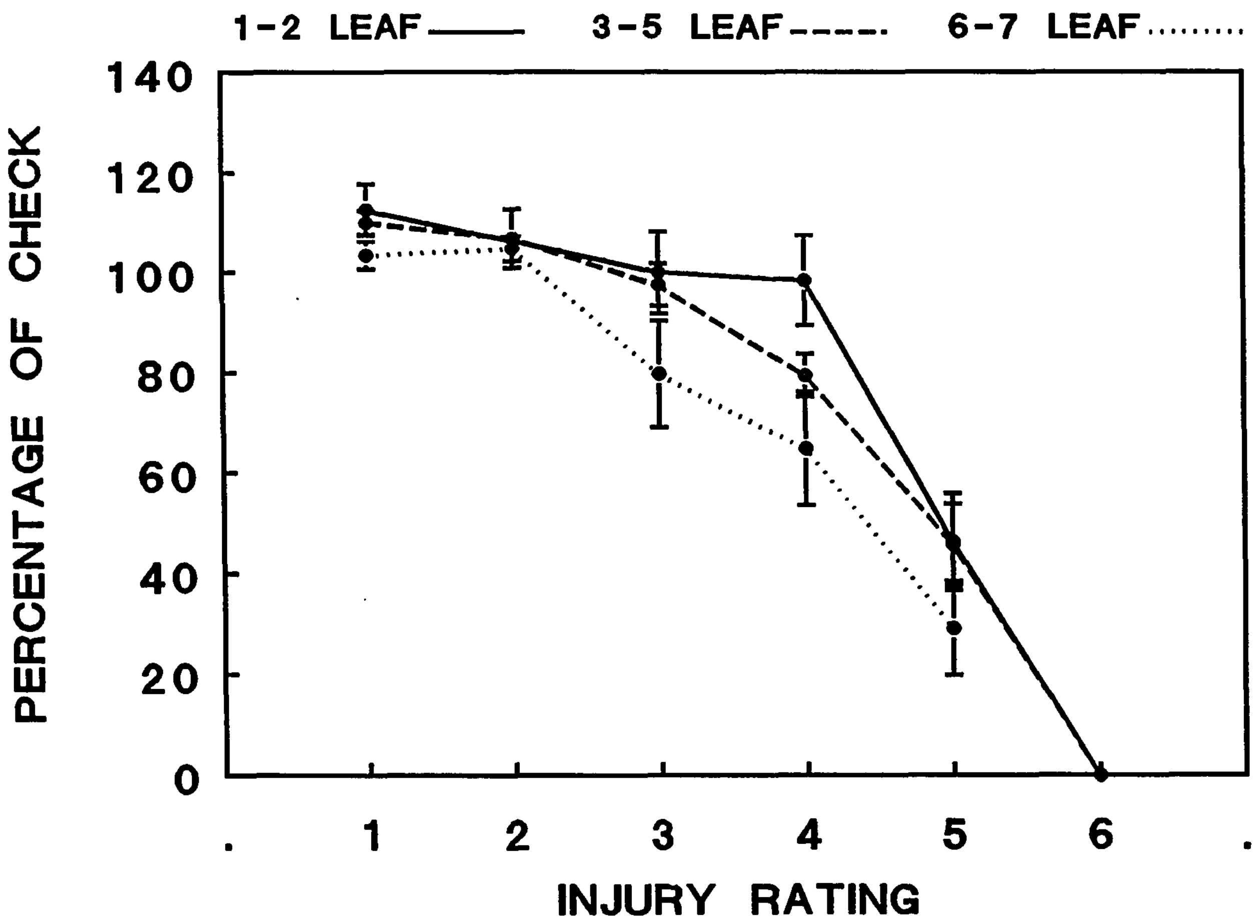


Figure 10. Average kernel weight (expressed as a percentage of the check) for various combinations of leaf stage and injury rating. Standard error bars represent variability between years and hybrids (N = 6)

Predicting Individual Plant Yield

Regression models were developed to predict grain yield, kernel number, and kernel weight for individual plants on the basis of injury rating (R) (Table 6). The addition of a second term, the average rating of a plot (AR), significantly improved all regressions. AR reflects the degree of competition between plants. Two factors which alter AR are the proportion of plants injured and the corn growth stage at the time of attack. To make direct comparisons across years and hybrids, all dependent variables were expressed as a proportion of the corresponding check for each hybrid and year combination.

In 1986 and 1987, curvilinear models best described the relationship between injury rating and the dependent variables. This relationship suggests that plants were able to tolerate some injury. In contrast, under the drought conditions of 1988, grain yield and number of kernels per plant declined linearly as injury rating increased. Similarly, research with the European corn borer, *Ostrinia nubilalis* (Hübner), has shown that damage per borer at a given infestation level was greater in dry seasons than in seasons with adequate moisture (Patch et al. 1942, Lynch 1980).

For all years and all yield components, the coefficients for average plot rating (AR) were positive. This implies that total yield, kernel weight, and number of kernels for an individual plant increase as the average rating of a plot increases. Thus, individual plants yield more, regardless of their individual injury rating, in stands that are less competitive. However, by maximizing an individual plant's yield, overall yield of the plot declines (see Section II).

Table 6. Coefficients (SE) and R^2 for equations used to predict individual plant grain yield, number of kernels, and kernel weight.[a] Dependent variables were expressed as a proportion of the check for the corresponding hybrid and year

Dependent variable	Year	Intercept	Rate	$Rate^2$	AR	R^2
Grain yield	1986	+0.865 (0.050)	--	-0.0438 (0.0026)	+0.141 (0.023)	0.53
	1987	+0.943 (0.044)	--	-0.0380 (0.0018)	+0.102 (0.019)	0.45
	1988	+0.997 (0.061)	-0.265 (0.015)	--	+0.162 (0.029)	0.33
	1986-87	+0.919 (0.033)	--	-0.0397 (0.0015)	+0.114 (0.014)	0.47
Number of kernels	1986	+0.896 (0.042)	--	-0.0400 (0.0022)	+0.103 (0.019)	0.59
	1987	+0.867 (0.052)	-0.097 (0.037)	-0.0481 (0.0060)	+0.056 (0.015)	0.50
	1988	+1.052 (0.058)	-0.265 (0.015)	--	+0.151 (0.028)	0.35
	1986-87	+0.946 (0.027)	--	-0.0350 (0.0012)	+0.071 (0.012)	0.53
Kernel weight	1986	+0.715 (0.067)	+0.172 (0.052)	-0.0548 (0.0078)	+0.072 (0.020)	0.44
	1987	+0.757 (0.059)	+0.252 (0.042)	-0.0664 (0.0068)	+0.057 (0.017)	0.35
	1988	+0.842 (0.064)	+0.110 (0.054)	-0.0489 (0.0087)	+0.022 (0.022)	0.33
	1986-87	+0.744 (0.045)	+0.226 (0.033)	-0.0624 (0.0052)	+0.061 (0.013)	0.37

[a]N = 320, 640, and 640 for 1986, 1987, and 1988, respectively.

Plants may be able to compensate for stalk borer infestations by increasing kernel number and, to a lesser extent, kernel weight. In previous studies with stalk borer, Bailey and Pedigo (1986) did not detect any increase in yield of plants adjacent to the injured plants. One reason may be that the initial infestation level was too low (one larva per 4 m of row) to induce compensation. Second, uninfested plot yields in 1983 and 1984 of the study averaged 43% and 66% lower, respectively, than in 1982. These low yields indicate that the corn was stressed, and uninfested plants may have responded as in our 1988 study.

SECTION IV.

ECONOMIC INJURY LEVELS FOR MANAGEMENT OF STALK BORER (LEPIDOPTERA: NOCTUIDAE) IN CORN

ABSTRACT

A computer program was developed to predict yield in corn, Zea mays L., infested by stalk borer, Papaipema nebris (Guenée), on the basis of injury profiles for each leaf stage and regression models for predicting yield of individual plants. Yield losses caused by stalk borer declined as corn was attacked later in development. Once the stalk begins to elongate (6-leaf stage), the ability of the stand to tolerate stalk borer injury sharply increases. However, yield loss in 6- and 7-leaf corn was much greater under drought stress than when moisture was adequate. Yield losses for selected leaf stages were comparable to those reported for black cutworm, Agrotis ipsilon (Hufnagel), and European corn borer, Ostrinia nubilalis (Hübner). Predictions from this model were used to calculate economic injury levels for corn attacked at leaf stages 1-7 under adequate moisture and drought conditions. A management program, which incorporates larval sampling in noncrop areas and prediction of movement on the basis of degree-day accumulations, is presented.

INTRODUCTION

Without a thorough understanding of the relationship between injury and yield loss, the decision to apply an insecticide can be a difficult and costly one. Economic injury levels (EIL) enable a grower to make a sound management decision when dealing with a particular pest. An insect for which EILs are lacking is the stalk borer, *Papaipema nebris* (Guenée). This sporadic pest of corn, *Zea mays* L., can cause significant yield reductions, especially in terraced or no-till fields (Levine et al. 1984, Lasack and Pedigo 1986).

Before EILs can be developed, information on the type and severity of injury inflicted by a pest is needed. The type of injury inflicted by stalk borer varies with developmental stages of the corn (see Section III). The injury profile shifts from a high incidence of severe injury at the 1- and 2-leaf stages of corn development to a high incidence of tunneling by the 7-leaf stage. Multiple regression models have been developed to predict yield of an individual plant from its injury rating and the average rating of plants in the surrounding area (see Section III).

In this paper, we present the results of a computer simulation model that predicts yield of corn under various infestation levels of stalk borer. Subsequently, the results of the simulations were used to derive EILs for the stalk borer.

MATERIALS AND METHODS

Predicting Yield

One of the goals of this research was to predict corn yields under various conditions of infestation level and leaf stage. Although injury rating is a better predictor of yield than infestation level (see Section II), assigning a rating to the plants may take several weeks of evaluations. A fairly simple computer program, written in BASIC, was developed to predict yields in fields infested by stalk borer. The model combines information concerning the injury profiles and the individual plant response to injury. Inputs to the model are yield potential, corn leaf stage, and infestation level.

Model Assumptions

To simplify the model, several assumptions were made. The first was that the proportion of plants in each injury and leaf-stage class does not vary with hybrid or weather conditions. The second assumption was that hybrids have characteristics similar to the two hybrids used to model the injury/yield relationship. The two hybrids, Pioneer hybrid 3541 and Pioneer hybrid 3377, are full-season hybrids for central Iowa and have the ability to adjust ear size in response to competition from neighboring plants. In addition, the maximum infestation rate is assumed to be one borer per plant. Although multiple stalk borers have been found in corn plants in fields with extremely high infestation levels, most plants are attacked by a single larva (Lasack and Pedigo 1986).

Model Equations

Individual plant yield is influenced by two major factors, the plant's injury rating (R) and the competitive influence of adjacent plants (see Section III). The latter factor can be represented by the average injury rating (AR) of all plants in the infested area. AR decreases as plants become older at the time of attack and increases with infestation level. The program calculates the expected AR for a given leaf stage (K) and infestation level (PINJ) as:

$$AR(K,PINJ) = (1 - PINJ) + PINJ*\sum_{R=2}^{6}(R*INJURY_{K,R}); \qquad K=1,..,7 \qquad (1)$$

where INJURY is the expected proportion of plants in injury class R at leaf stage K (Table 7).

A second function calculates the expected yield of individual plants on the basis of weather condition (1 = adequate moisture, 2 = drought stress), individual plant rating, and average plot rating.

$$YIELD(R,AR,STRESS=1) = 0.919 - 0.0397*R^2 + 0.114*AR \qquad (2)$$

$$YIELD(R,AR,STRESS=2) = 0.997 - 0.265*R + 0.162*AR \qquad (3)$$

Plot yield (PYLD), expressed as a proportion of the yield in an uninfested area, is computed by using the series of equations:

$$HYLD = (1 - PINJ) * YIELD(1,AR,STRESS) \qquad (4)$$

$$DAMYLD = PINJ * \sum_{R=2}^{6}(INJURY_{K,R} * YIELD(R,AR,STRESS)) \qquad (5)$$

$$PYLD = HYLD + DAMYLD \qquad (6)$$

where HYLD and DAMYLD are the yield contributions of healthy and damaged plants, respectively, expressed as a proportion. The model then computes the projected yield on the basis of the actual yield potential of the field.

Table 7. Matrix of proportions of injured plants for each leaf stage and injury class. Each proportion was estimated from two hybrids tested during 1986-1988 (see Section III)

	Injury rating[a]				
Leaf stage	2	3	4	5	6
1	0.007	0.136	0.272	0.231	0.354
2	0.013	0.190	0.253	0.354	0.190
3	0.019	0.207	0.368	0.368	0.038
4	0.069	0.314	0.176	0.428	0.013
5	0.076	0.219	0.324	0.381	0
6	0.450	0.200	0.200	0.150	0
7	0.759	0.148	0.050	0.043	0

[a]2, tunneling only; 3, leaf feeding exceeding 10%; 4, dead heart, growing point not injured; 5, dead heart, plant tillered; 6, killed.

RESULTS AND DISCUSSION

Validation of Model

To validate the model, yield predictions were compared with actual yields for 17 plots. Yields and infestation levels for seven plots used in the validation were reported by Levine et al. (1984). These plots were infested with natural populations of stalk borer and were located near Cisco, Illinois and Maroa, Illinois. Yield potential for each field was estimated by the average yield of uninjured plants. Because natural populations of stalk borer may injure corn over a period of time, the corn growth stage at the beginning of the period was used in testing the model. Data for the remaining 10 plots were obtained from studies conducted during 1988 and 1989, which tested hybrids for tolerance to stalk borer (unpublished data). Plots were infested with stalk borer when corn was either 2-leaf or 4-leaf stage. Uninfested plots were used to estimate the yield potential. Plot yields ($\underline{Y}$) were compared with predicted yields ($\underline{X}$) by using linear regression. The model did a good job in predicting yields of corn infested by stalk borer (Fig. 11). The regression had an overall R^2 of 0.91.

Model Predictions

Model predictions for various weather, leaf-stage, and infestation-level combinations are illustrated in Fig. 12. In general, yield losses caused by stalk borer declined as plants were attacked later in development. Once the stalk begins to elongate (6-leaf stage), the ability of the stand to tolerate stalk borer injury sharply

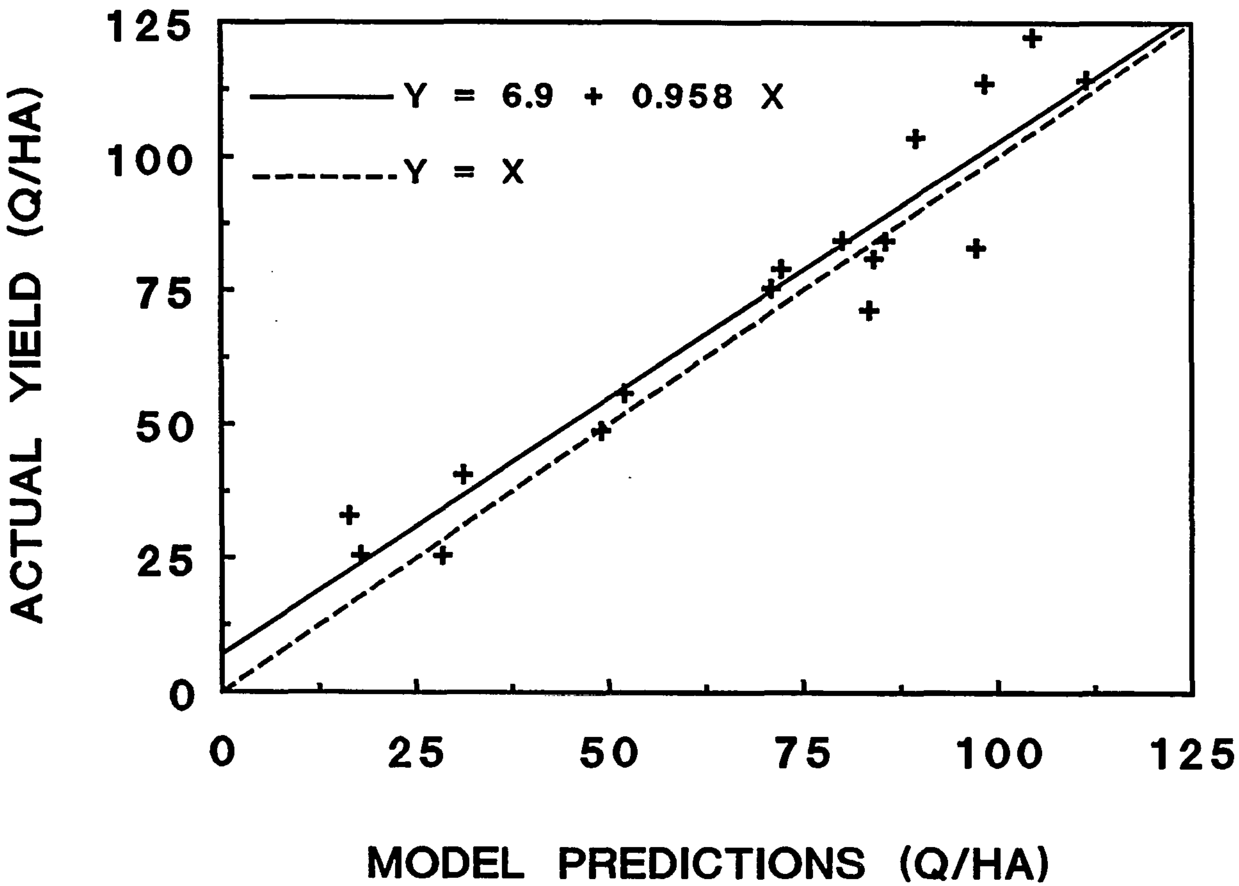


Figure 11. Comparison of model predictions with actual grain yield for 17 plots infested with stalk borer

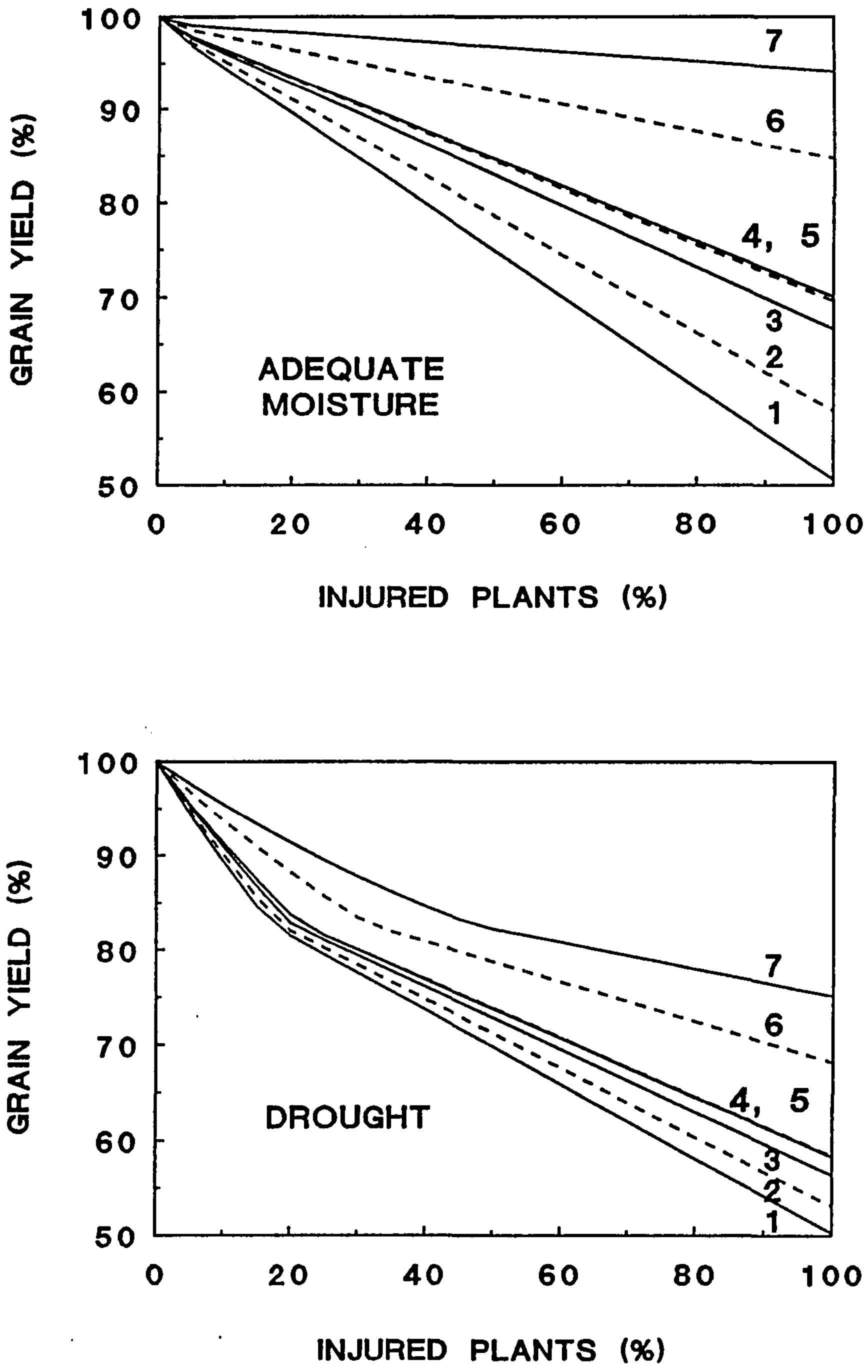


Figure 12. Predicted grain yield for corn infested with stalk borer larvae. Numbers indicate the leaf stage of the corn at the time of attack. Simulations were run under (a) adequate moisture and (b) drought conditions

increases. In addition, moisture stress strongly influences yield losses, especially in older plants. Corn attacked at the 7-leaf stage loses about 6% of its total yield when 100% of the plants are injured and moisture is adequate. However, losses may reach 21% under drought conditions.

Comparison of Stalk Borer With Other Early-season Pests

We can compare the injury/yield loss relationship of stalk borer with other early-season pests of corn. Like the black cutworm, Agrotis ipsilon (Hufnagel), the stalk borer, primarily, is a stand reducer when very young corn is attacked. Troester (1982) used a computer simulation program to determine losses occurring for various combinations of crop stage and larval instars for the black cutworm. On the basis of tabular data presented by Troester, an additional 10% injury (cut plants and tunneling only) from fifth- instar black cutworm would produce yield losses of 5.8%, 6.4%, 7.4%, and 7.8% at leaf stages 1-4, respectively. By adjusting stalk borer injury to exclude leaf feeding, yield losses of 6.0%, 5.6%, 4.9%, and 4.8% would be expected at leaf stage 1-4, respectively, for comparable injury levels.

First-generation European corn borer, Ostrinia nubilalis (Hübner) is another early-season pest and causes both leaf feeding and stalk tunneling. One European corn borer per plant would cause a 5.5% reduction in yield when corn is in the early whorl stage at the time of attack (Showers et al. 1989). Similarly, 7-leaf corn, attacked by stalk borers, would lose 5.8% of the potential yield when 100% of the plants are attacked and moisture is adequate.

Table 8. Economic injury levels for corn attacked by stalk borer. EILs are expressed as a percentage of the plants injured and based on corn price of \$7.87/q, management cost of \$24.70/ha, and a 50% reduction in pest attack[a]

	EIL under adequate moisture		EIL under drought stress	
Leaf stage	78.4 q/ha	94.1 q/ha	31.4 q/ha	47.1 q/ha
1	15.0%	12.0%	24.0%	13.0%
2	18.0	14.5	26.0	14.0
3	22.5	18.5	28.0	15.0
4	24.8	19.8	30.0	16.2
5	25.2	20.6	30.0	16.1
6	50.5	41.0	45.0	23.0
7	> 100	> 100	66.0	33.0

[a]1 q/ha = 1.59 bu/a.

Economic Injury Levels

Based on the model projections for grain yield in corn infested by stalk borer, relatively conservative EILs were calculated for various infestation levels and corn-growth stages (Table 8). All EILs were determined by (1) calculating the gain threshold (Stone and Pedigo 1972) and (2) determining the infestation level associated with the loss. In these calculations, we assumed that the insecticide would produce a 50% reduction in pest attack. In several insecticide trials, the reduction in the number of injured plants in treated areas compared with untreated areas ranged from 40 to 89% (Wedberg et al. 1983, see Section V). For this example, management cost (fenvalerate or permethrin) and market price of corn were set at \$24.70/ha (\$10/a) and \$7.87/q (\$2.00/bu), respectively. The calculated EILs under normal and drought conditions are very similar for corn at the 5-leaf stage or younger. In contrast, EILs for 6- and 7-leaf corn are much lower if plants are under drought stress.

Management of Stalk Borer

One of the difficulties in managing stalk borers is that larvae usually are not vulnerable to insecticide once they bore into the stalk. In addition, plants may be killed or severely injured by larvae within a matter of days after infesting young corn (see Section II). Thus, timing of insecticide application is critical to successful management of stalk borer.

The EILs presented in this paper are most useful when incorporated into a management program for stalk borers associated with grassy terraces and field edges. The first step to reduce losses is to estimate the larval population. Sampling noncrop areas provides an effective method for estimating stalk borer density before corn is attacked. The easiest time to sample these areas is after 500 to 600 CDD have accumulated (base 5.1°C, accumulated from 1 January). At this time, most stalk borers are large enough to have killed the grass stem in which they are tunneling, but they have not moved into the corn. By locating and carefully dissecting grass stems that are wilted and/or turning brown, an estimate of the stalk borer density in noncrop areas can be made (Davis and Pedigo 1989).

Potential damage to corn can be predicted on the basis of stalk borer density in grass. The average number of larvae (X) per 900-cm^2 quadrat within grassy areas is related to the percentage of injured plants (Y) within the two rows of corn adjacent to the grassy area as $Y = 52.3 + 26.8(\ln X)$ (Lasack and Pedigo 1986). For example, populations of 0.3 and 1.0 larva per quadrat correspond to 20% and 52% of the plants injured within the two rows adjacent to the grass, respectively.

The economic threshold for stalk borer depends upon the corn leaf stage when larvae are moving, as well as on the population of larvae in the grass. In another study, a degree-day model was developed to predict movement of larvae from grassy areas (see Section V). The model predicts that 10%, 30%, and 50% of the stalk borers will move out of the grass by 755, 850, and 920 CDD, respectively. Consequently, we recommend scouting the corn for stalk borers after 700 CDD have accumulated to verify movement of larvae. Finally, the corn leaf stage and prevailing weather patterns should be determined after 800-850 CDD have accumulated. If potential injury, as estimated by the number of stalk borers in the grass, exceeds the EIL, an insecticide application should be considered. Limited testing on the impact of timing of insecticide applications have detected no difference in efficacy, as measured by number of injured plants, when treatment is applied between 875 and 1000 CDD (see Section V). However, since younger plants are more susceptible to severe injury, an insecticide application during the early phase of movement may be preferable.

In the situation where eggs were laid on weedy grasses within a corn field, such as in a no-till cropping system, the EILs presented in this paper could serve as guidelines. However, application of herbicides may force premature movement of larvae. Very young stalk borers may not produce the same ratios of injury to corn as older larvae, necessitating further research to validate the yield-loss model.

SECTION V.

EVALUATION OF TWO MANAGEMENT STRATEGIES FOR STALK BORER, *PAPAIPEMA NEBRIS*, IN CORN

ABSTRACT

Two models, one to predict stalk borer (*Papaipema nebris* Guenée) development and the other to predict larval movement from grass terraces to corn, were used to time applications of the insecticide, permethrin. Both models were based upon degree-day accumulations from 1 January and used a developmental threshold of 5.1°C. Permethrin, applied during the egg-hatch period, significantly reduced stalk borer density in smooth brome (*Bromus inermis* Leyssera) terraces by 54-85% over untreated plots during 1986 and 1987. Applications of permethrin that were timed to coincide with larval movement, however, were more effective in reducing severe damage to plants in corn rows adjacent to terraces than applications during egg hatch in 1987. This study suggests that using degree-day models to time insecticide application may be a viable strategy for stalk borer management.

INTRODUCTION

Management of the stalk borer, *Papaipema nebris* (Guenée) (Lepidoptera: Noctuidae), has become a difficult challenge for many corn growers in the midwestern United States. Although the stalk borer is not considered to be a major pest of corn, fields with grass terraces and waterways or reduced-tillage fields with poor fall grass control can sustain heavy losses. The life cycle of the stalk borer begins when moths oviposit on many species of grass during late August through October. High populations of stalk borer have been associated with the perennial grasses, smooth brome (*Bromus inermis* Leyssera) and orchard grass (*Dactylis glomerata* L.) (Lasack and Pedigo 1986, Stinner et al. 1984). After eclosion in the spring, young larvae generally bore into grass stems and continue to feed until the food supply runs out or the larvae become to large for the stem (Decker 1931). The larvae then search for a suitable large-stemmed host.

In most instances, injury to corn occurs either when newly eclosed larvae tunnel into a nearby corn plant (such as in no-till situations) or when half-grown larvae move from grassy areas in search of a new host plant. In the latter instance, injury is limited to four to eight rows of corn adjacent to the grassy area. Supression is difficult because larvae are exposed for a relatively short time, coinciding with egg hatch and movement between host plants. In recent years, research has been conducted to model stalk borer development and movement (Levine 1983, 1986, Lasack and Pedigo 1986, Lasack et al. 1987). The main objectives of this study were to evaluate the accuracy of development and movement models and to determine if insecticide efficacy could be improved by timing application with egg hatch and movement.

MATERIALS AND METHODS

Plot Design

This study was conducted in a terraced cornfield located in Jasper County, Iowa, USA. Corn was planted on 21 May 1986 and 14 May 1987. Smooth brome was the predominant grass species in the terraces. In 1986, treatments were arranged in a randomized block design with four replications. Each plot measured 6.1 m x 6.1 m and was oriented so that half of the plot, 6.1 m x 3.05 m, was grass terrace and half was corn. Treatments consisted of two unsprayed check plots and five insecticide plots per block. Application of the insecticide permethrin was timed to coincide with either stalk borer egg hatch or larval movement from grass to corn (29 April, 2 May, 6 May, 3 June, and 13 June). A sixth spray treatment was planned initially to coincide with initial larval movement. The treatment was dropped because of delayed corn emergence and subsequently treated as a check in the final analysis. At the designated times, permethrin was applied at a rate of 0.224 kg ai/ha in 168.4 l water/ha. Pressure was maintained at 3.5 kg/cm^2. Insecticide was applied with a Suzuki LT-125 4-wheel, all-terrain vehicle equipped with a 6.1-m, CO_2-charged boom fitted with 12 brass 8004 flat-fan nozzles (Hutchins and Pedigo 1987).

In 1987, plots were arranged in a split-plot design with four replications. Individual plots measured 14 m x 6.1 m and were situated so that half of the plot, 14 m x 3.05 m, was grass terrace and half was corn. Plots were grouped as either early treatments (at egg hatch) or late treatments (at stalk borer movement). The treatments within each group consisted of one check plot and three plots treated with permethrin. Early applications were applied on 27 April, 30 April, and 5 May. Late application treatments consisted of two single applications on 1 June and 8 June and one double application on 1 June and 8 June. The insecticide application methods were the same as in 1986.

Egg Hatch and Movement Models

Two temperature-driven models were used to time insecticide applications to egg hatch and larval movement. Lasack et al. (1987) modeled stage-specific development of natural populations of stalk borer by using logistic regression equations. For our current study, we predicted egg hatch by using the model that Lasack et al. (1987) developed to predict appearance of first instars during years with low April rainfall. April rainfall during our study totaled 8.20 cm in 1986 and 5.18 cm in 1987 and was more similar to the year with low April rainfall (2.34 cm) than to the year with high April rainfall (17.09 cm). The proportion of larvae that reached or exceeded the first instar (P_1) was related to degree days (X) accumulated from 1 January (Equation 1). This model used the lower development threshold of 5.1°C proposed by Levine (1983) for total development from egg to adult.

$$P_1 = (1 + \exp(9.95 - 0.0292\ X))^{-1} \qquad (1)$$

In a 2-year study, stalk borer movement from grassy areas into corn was monitored with linear pitfall traps (Lasack and Pedigo 1986). On re-examination of the capture data, we found that the proportion of stalk borers caught in the traps (P_t) was related to degree day accumulations (X) above a base temperature of 5.1°C. This model was used to time the application of insecticides to correspond with stalk borer movement.

$$P_t = (1 + \exp(26.091 - 5.29E\text{-}2\ (X) + 3.4E\text{-}5\ (X)^2 - 8.3E\text{-}9\ (X)^3))^{-1}$$

$$R^2 = 0.942 \qquad (2)$$

Temperature and precipitation data were obtained from the National Oceanic and Atmospheric Administration weather station (NOAA) in Newton, Iowa, located 11 km SE of the research field. Centigrade degree day accumulations (CDD) from 1 January were calculated by using the sine-wave method from the computer program DEGDAY (Higley et al., 1986).

Sampling

Grass samples were collected on 20 May 1986 (595 CDD) and 19 May 1987 (676 CDD) from one check plot and three hatching-time plots per block. For each plot, all plant material in three randomly selected, 930-cm^2 quadrats was clipped at ground level, bagged, and returned to the laboratory. Grass stems were split open to locate tunneling larvae. Larvae were counted and staged according to head-capsule measurements (Lasack et al. 1987).

Weekly grass and corn samples were collected from 2 June to 1 July 1986 and 27 April to 23 June 1987 and used to monitor stalk borer development and movement in areas directly adjacent to treated plots. In 1987, egg hatch was estimated by dividing the density present on 27

April and 5 May by the maximum density observed in the grassy areas. Similarly, movement was estimated by dividing the number of injured plants in the sampled area by the maximum number of injured plants observed on the final sampling date during each year.

In 1986, corn populations and damage ratings were recorded on 19 June for the three rows of corn within all plots. Each plant was classed as undamaged, minor leaf feeding, heavy leaf feeding, dead heart (whorl cut off), or tunneled. At this time, giant ragweed, _Ambrosia trifida_ L., was observed in irregular patches throughout the terraces. Because giant ragweed is highly attractive to moving stalk borer larvae, a second sample was taken on 1 July. For each plot, all broadleaved plants within a 3 m x 3 m area of terrace and 3 row-m of corn in each of the two rows closest to the terrace were destructively sampled and returned to the laboratory for dissection. In 1987, final stand and damage ratings were recorded on 15 June for the three rows of corn within each plot. Ragweed populations were very low, and a destructive sample was not taken.

To evaluate stalk borer numbers in grass samples and damage ratings for the 1986 study, analysis of variance procedures for a randomized block design and subsequent separation of means with Duncan's multiple range test ($p=0.05$) were used. For the split-plot analysis of damage ratings in 1987, treatment differences within early and late spray groups were discriminated by using least significant differences (LSD) at $p=0.05$.

RESULTS AND DISCUSSION

Model Validation

Degree-day accumulations, stalk borer development, and crop development are presented in Table 9 for each spray date. Random checking of grass stems at the time of the early insecticide applications confirmed the presence of first-instar stalk borers during both years. Model predictions and field estimates were very similar and differed by 7% or less in 1987. Other degree-day models have been proposed to predict egg hatch on the basis of growth-chamber studies (Levine 1986). Using a base temperature of 8.9°C for egg development, Levine (1986) found that 209.5 CDD were required for 50% egg hatch under constant temperatures in growth chambers. If Levine's model is applied to our field conditions, 50% egg hatch is projected to occur on 30 April 1986 and 28 April 1987. These dates are very similar to our field observations and projections from model (1).

In using a degree-day driven model to predict stalk borer movement, we were able to time insecticide applications with movement. However, the accuracy of the model varied with the year. In 1986, the model overestimated movement by 4 days and 8 days for the 3 June and 13 June treatments, respectively. In contrast, movement was overestimated by 5 days on 1 June 1987 and underestimated by 1 day on 8 June 1987. One source of variation may be that the model was based upon 2 years of pitfall capture data, whereas movement in this study was estimated by the increase in damaged plants within the corn. However, a second factor, rainfall during May, probably plays an important role in

Table 9. Field observations and model predictions for egg hatch and larval movement on days when permethrin treatments were applied

Spray Date	CDD	Model Projection	Field Estimation	Average Stage of Larvae	Grass Height (cm)	Corn Stage[a]
4/30/86	340	39% Hatch	--	--	30-38	Not up
5/ 2/86	364	62% Hatch	1st Instars Found	--	51-61	Not up
5/ 6/86	417	86% Hatch	--	--	58-71	Not up
6/ 3/86	784	18% Movement	8% Movement	3.89	70-80	1 leaf
6/13/86	959	67% Movement	30% Movement	5.06	70-80	3 leaf
4/27/87	351	57% Hatch	50% Hatch	1.55	23-30	Not up
4/30/87	391	81% Hatch	--	--	35-46	Not up
5/ 5/87	447	96% Hatch	90% Hatch	1.69	41-56	Not up
6/ 1/87	878	44% Movement	20% Movement	3.99	58-76	3 leaf
6/ 8/87	994	74% Movement	75% Movement	5.16	58-76	5 leaf

[a]Corn developmental stages as described by Ritchie et al. (1986).

determining grass stem diameter and subsequent movement of larvae. Normal rainfall during May at the Newton, Iowa, station is 10.46 cm (NOAA report, May 1988). As illustrated in Figure 13, the delayed movement during 1986 occurred in a year when May rainfall was 56% above normal. Movement and May precipitation were very similar in 1984 and 1987 when rainfall amounts were near normal. In contrast, the below-normal precipitation in May 1985 coincided with earlier larval movement.

Insecticide Performance

During both years, early-season applications of permethrin were effective in reducing stalk borer populations in the terraces by 50% or more when compared with the check (Table 10). In 1987, some loss in effectiveness was observed for the treatment on 5 May. On this date, the average stadium of sampled larvae was 1.69. Although first instars may feed on grass leaves, most second instars tunnel into grass stems and are shielded from insecticide contact. On the basis of this study, the most effective time to apply permethrin for early-season suppression of stalk borer is between 300 and 400 CDD (base temperature 5.1°C).

In 1986, no significant differences in number of injured corn plants or in the number of larvae recovered from the plots were detected between treatments on either 19 June or 1 July. The mean percentage of damaged plants ranged from 27 to 48% in row 1 and 8 to 20% in row 2. Evaluations on 1 July showed a 40% reduction in severe damage in row 1 for treatments applied on 30 April, 2 May, and 13 June when compared to the check; however this difference was not significant. The high variability may, in part, be attributed to presence of giant ragweed

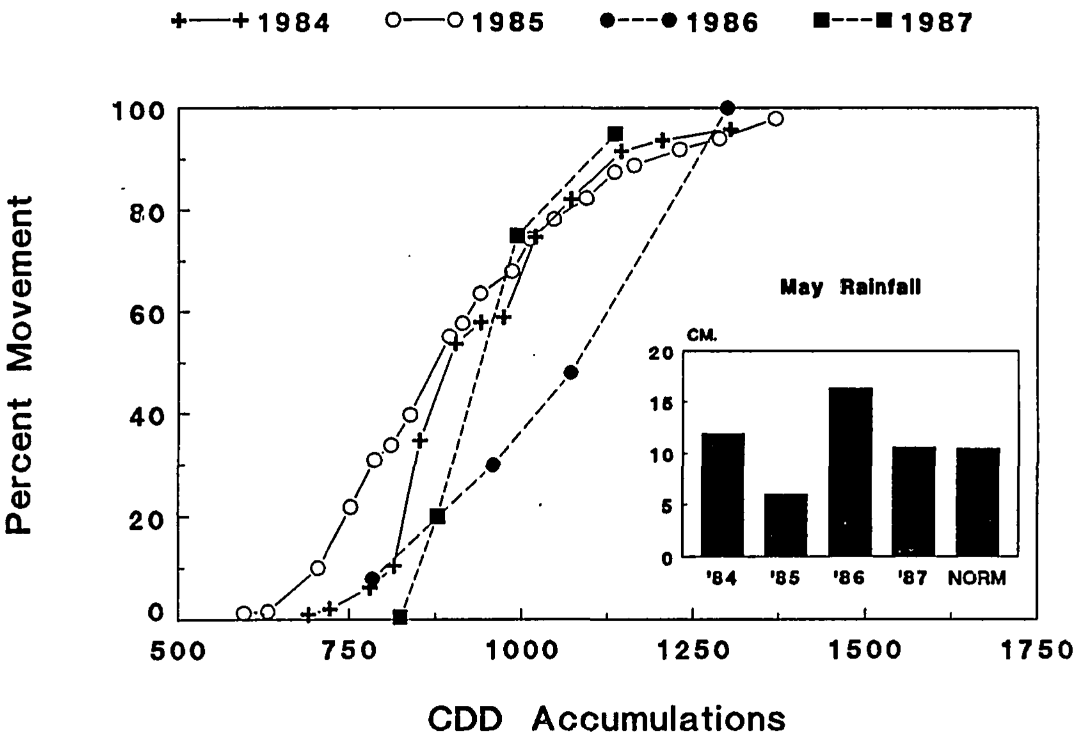


Figure 13. Comparison of stalk borer movement and degree day accumulations from 1 January of each year (base temperature, 5.1°C). Percentage movement for 1984 and 1985 is based on pitfall trap captures reported by Lasack and Pedigo (1986). Movement in 1986 and 1987 is based on random field estimated of the number of damaged plants in rows adjacent to terraces. Inset shows May rainfall.

Table 10. Mean number of stalk borers per 930-cm^2 quadrat in smooth brome plots treated with permethrin during egg hatch. Samples were collected on 20 May 1986 and 19 May 1987. Means followed by the same letter within a column are not significantly different at the 5% level as indicated by Duncan's multiple range test

1986		1987	
Treatment	Mean/quadrat	Treatment	Mean/quadrat
29 April	0.83 b	27 April	1.42 b
2 May	0.67 b	30 April	1.17 b
6 May	0.67 b	5 May	1.83 ab
Check	4.50 a	Check	4.00 a

within the terraces. Giant ragweed is a preferred host of stalk borer larvae. Populations of giant ragweed ranged from 0 to 68 plants in the sampled area on 1 July. With the number of giant ragweed plants used as a covariate, the total number of stalk borer larvae recovered from each plot was highly dependent upon the giant ragweed population ($F_{(1,18)} = 24.95$, $p < 0.0001$), although no differences were detected between treatments ($F_{(5,18)} = 0.69$, $p = 0.65$). Because the plots were fairly small, giant ragweed may have attracted moving larvae from neighboring plots and further have masked treatment differences.

In 1987, insecticide applications during larval movement from grass to corn were moderately effective in reducing severe damage to the corn (Figure 14). No significant advantage was gained from two applications of permethrin. On the average, insecticide treatments reduced severe

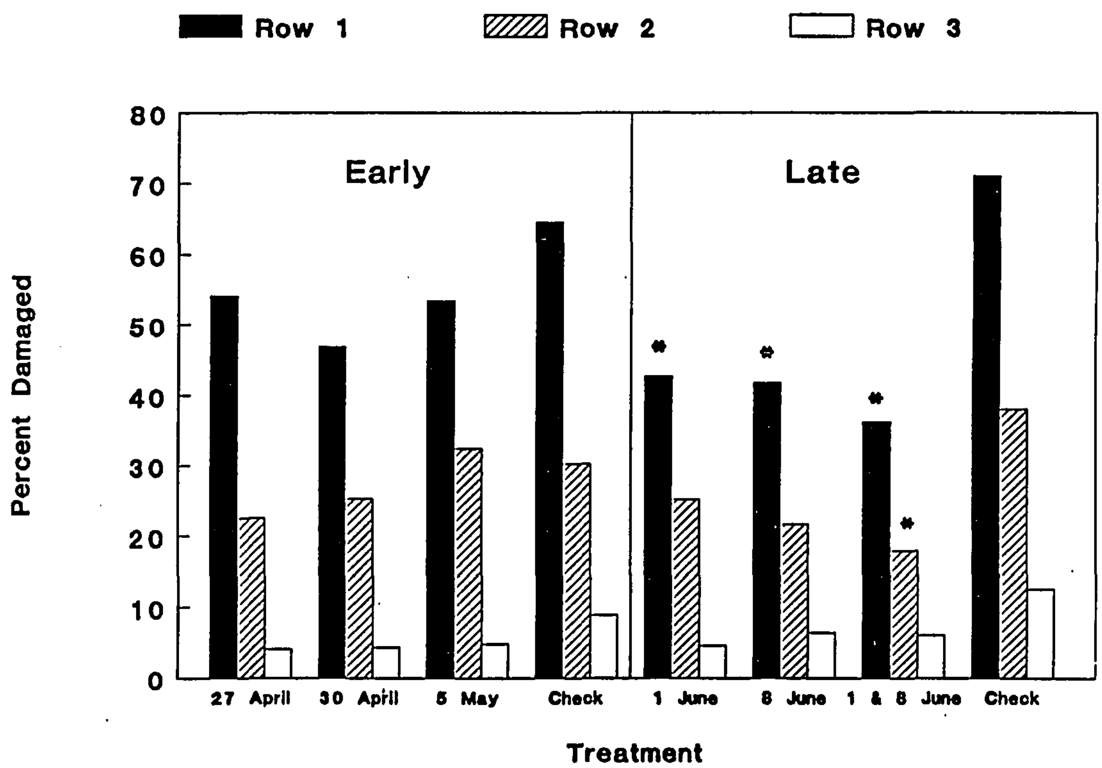


Figure 14. Mean percentage of corn plants with severe damage (heavy leaf feeding, dead heart, or tunneled) on 15 June 1987. A star above a bar indicates a significant difference between a treated plot and the corresponding check plot for a given row (based on LSD of 0.186, 0.172, and 0.080 for rows one, two, and three, respectively, p = 0.05, df = 18).

damage by 43%, 43%, and 54.5% for rows 1, 2, and 3, respectively, when compared with the check.

Application of permethrin during the egg-hatch period during 1987 generally was not effective in reducing severe damage to corn, although some suppression was noted (Figure 14). Although significant reductions in stalk borer density in the terraces were noted for the early applications of permethrin, stalk borer populations in treated plots still were sufficiently high to cause substantial damage to adjacent corn rows. Stalk borer densities of 1.0 larvae/930-cm^2 quadrat may lead to 50% or more damage to plants within the first two rows of corn (Lasack and Pedigo, 1986). If insecticides are applied during the hatch period, we recommend that populations in treated areas be monitored before 650 CDD to evaluate insecticide effectiveness.

Other researchers have attempted to reduce stalk borer damage with insecticide applications. In three studies conducted in Wisconsin, Wedberg et al. (1983) applied the insecticide, fenvalerate, to corn rows bordering grass after stalk borer feeding was observed. The total number of damaged plants in row 1 was reduced by 41%, 59%, and 89% when compared with untreated areas. The results of our 1987 study, which timed insecticide application on the basis of predicted movement, obtained results comparable to those of Wedberg et al. (1983).

To determine whether application of permethrin to terraces and the adjacent three rows of corn was economically feasible in 1987, benefit:cost ratios were calculated. Corn plants damaged at the third through fifth leaf stage yielded an average of 67.3% less than uninjured plants (Levine et al. 1984). The benefit:cost ratios for one application during egg hatch, one application during movement, and two applications during movement were 1.03:1, 2.47:1, and 1.87:1, respectively, based on projected yield of 88 q/ha, corn price of $9.85/q, and chemical cost of $19.75/ha.

Because of their tunneling activity, stalk borers are vulnerable to insecticides for a limited time coinciding with egg hatch and movement from grass hosts to corn or other large-stemmed plants. Thus, use of development and movement models to time insecticide applications shows promise as a management strategy for stalk borer.

SECTION VI.

SBMGMT: A PHENOLOGY AND YIELD LOSS COMPUTER MODEL FOR MANAGEMENT OF STALK BORERS (LEPIDOPTERA: NOCTUIDAE) IN CORN

ABSTRACT

A simulation model, SBMGMT, was developed to forecast stalk borer (*Papaipema nebris* (Guenée)) phenology and predict corn yield losses in terraced and no-tillage farming systems. The temperature-driven model is written in BASIC and includes subcomponents which forecast stalk borer egg hatch, movement of larvae out of grass, corn developmental stages, and yield loss. Inputs such as planting date, population densities, weediness of field, herbicide application date, and yield potential can be varied. A graphics routine allows the user to time insecticide applications on the basis of predicted stalk borer movement and stage of corn development. SBMGMT simulations indicate that cultural practices, as well as timing and placement of insecticide can significantly alter injury and yield loss.

INTRODUCTION

The stalk borer, Papaipema nebris (Guenée) (Lepidoptera: Noctuidae), can cause significant yield losses to corn grown in terraced fields and fields that are no-tilled (Stinner et al. 1984, Levine et al. 1984, Lasack and Pedigo 1986). Management of stalk borers in these systems is difficult because larvae can cause significant losses in a matter of days (Section II). However, larval migration out of grassy areas may take place over a period of several weeks (Lasack and Pedigo 1986). In addition, the tunneling activity of larvae into plant stems permits exposure to insecticides during a limited period of time. Currently, mathematical models have been developed to predict stalk borer development (Lasack et al. 1987), larval migration (Section V), and injury/yield loss relationships (Section III). One method for incorporating available information on stalk borers and testing management alternatives is through simulation modeling.

This paper reports on the development and validation of SBMGMT, a management model to predict stalk borer phenology and yield losses in corn. The model was formulated with three primary objectives: (1) to accurately forecast egg hatch, larval movement, and stage of corn development, (2) to predict yield losses to corn in terrace and no-tillage systems, and (3) to evaluate the effectiveness of herbicide application, planting date, and insecticide programs in reducing yield losses.

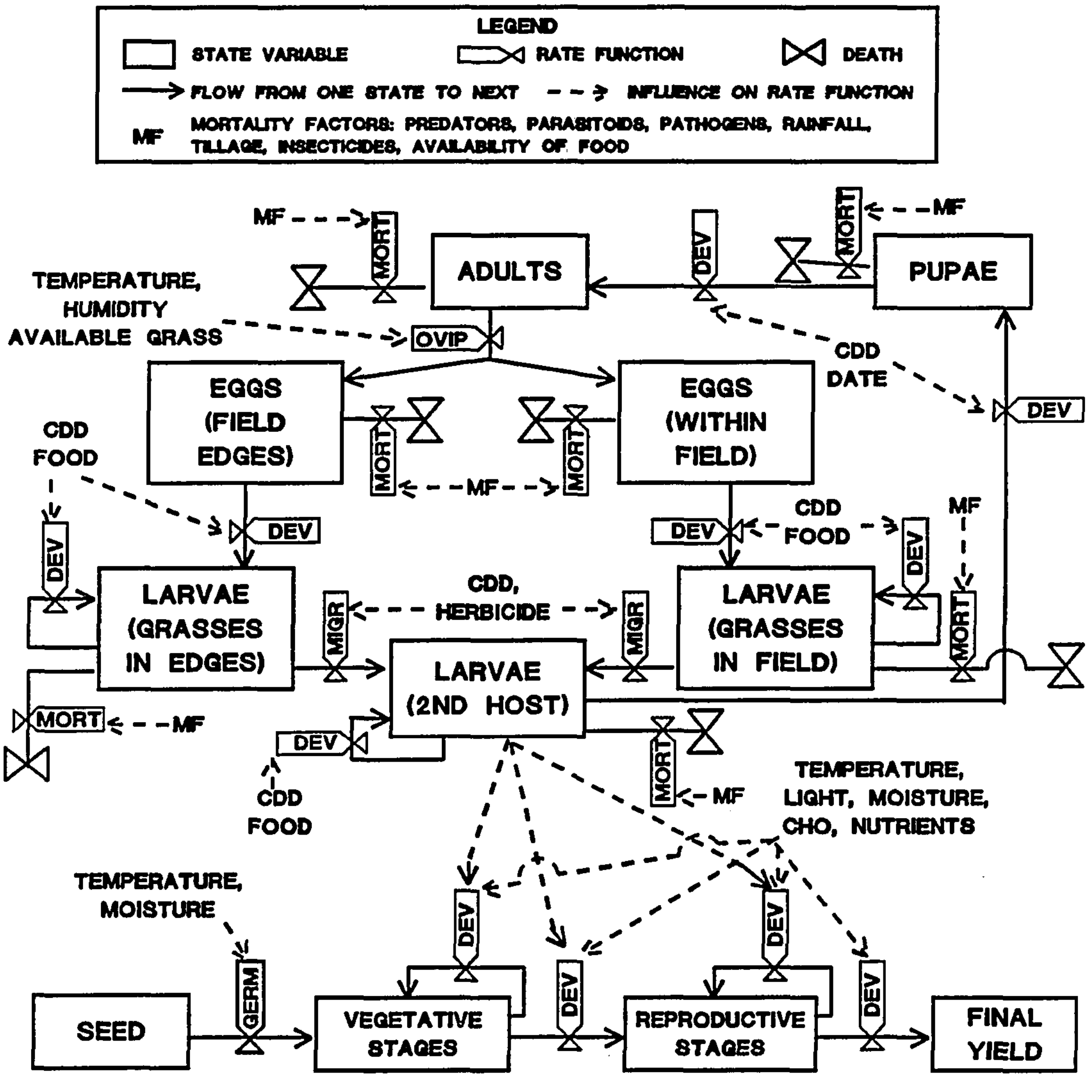


Figure 15. Conceptual model of stalk borer/corn system. Rate functions associated with mortality (MORT), development (DEV), oviposition (OVIP), migration (MIGR), and germination (GERM) are indicated

MODEL FORMULATION

A conceptual model of the stalk borer/corn system is illustrated in Figure 15. The stalk borer life cycle is characterized by a single generation per year. Moths oviposit eggs during the fall on a variety of grasses either growing within the field or in field edges and terraces. The overwintering eggs hatch during late April and May. Larvae initially feed within grass stems before migrating to a larger host plant, such as giant ragweed (Ambrosia trifida L.) and corn. Although movement from grasses is related to larval development and stem size, application of herbicides may force young larvae to move to corn earlier than expected. Damage to corn plants is in the form of defoliation, tunneling, and destruction of the growing point. The severity of injury depends upon the stage of corn development at the time of attack. In late July and August, mature larvae pupate either in the tunnel of the host plant or in the soil. Moth flight occurs from August throught October with peak flight occuring from 7-14 September (Bailey et al. 1985a)

Description of the Model

SBMGMT is a dynamic, deterministic, temperature-driven model. The model is written in Microsoft QuickBASIC and developed on a Zenith 286 microcomputer. SBMGMT uses degree days (^{o}C) to calculate corn development, stalk borer development, and movement out of grasses for the period from 1 January through 31 July. Time in days is used for all other calculations. The time step for the model is 1 d. SBMGMT consists of a main program and 13 submodels (subroutines and functions).

A simplified flow chart for the program is given in Figure 16. The system boundaries are defined as either (1) a grassy, noncropped area (waterway, terrace, or field edge) and 8 corn rows directly adjacent to this area or (2) a corn field of dimensions specified by the user. Multiple runs are required to compare modifications in cultural practices, such as altering dates for herbicide application and planting. For multiple runs, the program is equipped with an editor which allows changes in some or all of the input parameters.

Model Inputs

Two files, containing current and 20-year average temperature and rainfall data for each day, are accessed by the program. The program then requests beginning and ending Julian dates for the current weather file. A new weather file, containing daily temperatures and rainfall amounts from 1 January to 1 August, is created from the two input files such that any data missing from the current file is replaced with information from the 20-year average weather file. A detailed listing and description of all input parameters is found in Table 11. Data on field dimensions, crop parameters and stalk borer densities are input by the user via the computer keyboard. Stalk borer densities in noncrop areas, in number of larvae per square foot (930 cm^2), either can be estimated at egg hatch as low, medium, high, or very high or determined from actual sampling data collected after egg hatch but before larvae begin to move. The optimal time to collect these data is when 500-600 CDD have accumulated (Davis and Pedigo 1989).

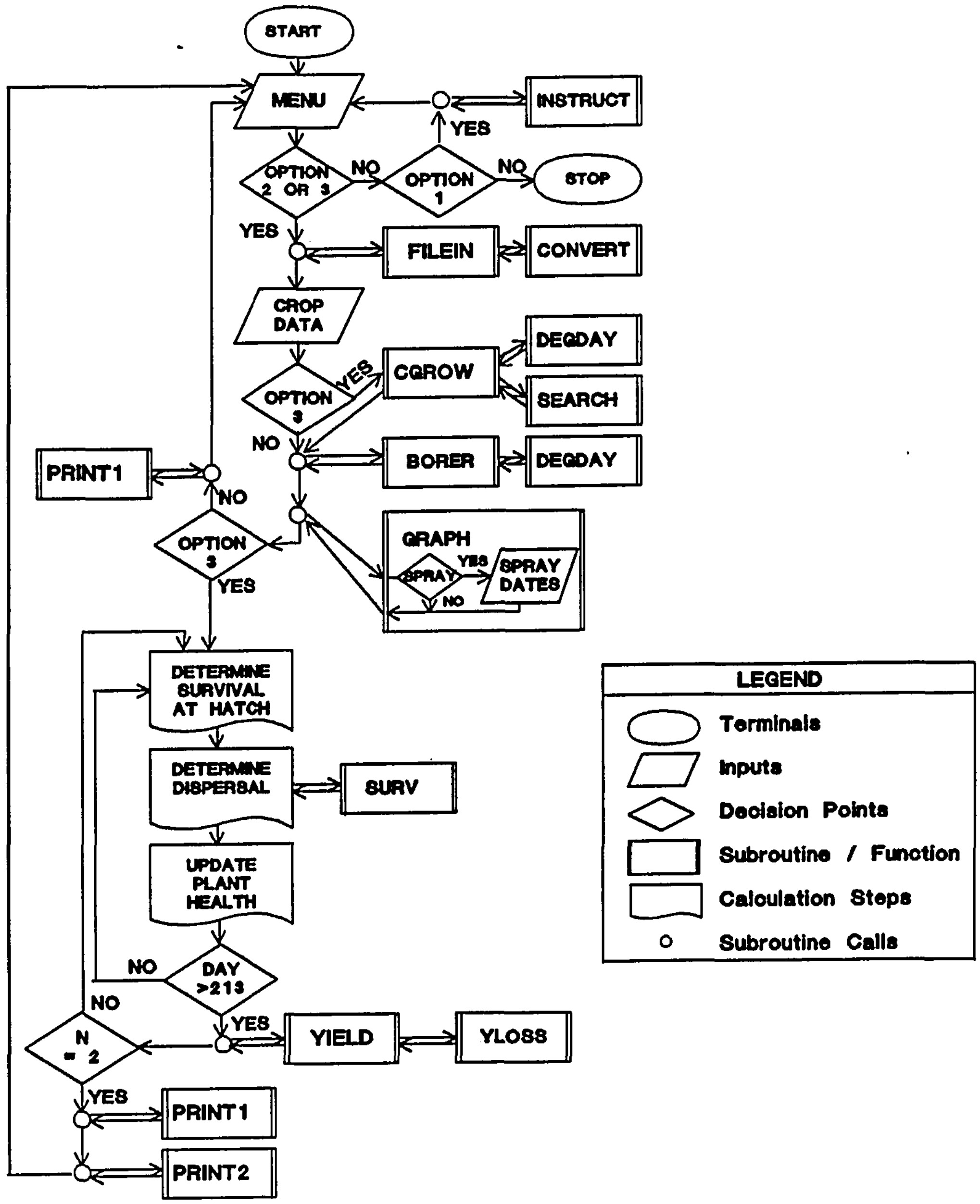


Figure 16. Flow chart for SBMGMT model

Table 11. Input variables required to run the yield portion of SBMGMT

Variable name	Description
NAME1	Name of file containing current weather data
NAME2	Name of file containing 20-year average weather data
YEAR	Year current weather data was collected
POTYLD	Yield potential of the field (bu/a)
JPLANT	Julian date corn is planted
MDD	Degree days required for hybrid to reach maturity (°F)
PPOP	Plant population per acre
RWIDTH	Row width (inches)
SOIL	Soil moisture condition at planting (adequate or dry)
TLENGTH	Length of terrace or other noncrop area (feet)
TWIDTH	Width of terrace or other noncrop area (feet)
FLENGTH	Field length (feet), required if noncrop area is absent
FWIDTH	Field width (feet), required if noncrop area is absent
GC	Number of grass clumps per yard of row
SBG	Density of larvae in noncrop areas (larvae/ft^2)
SBF	Density of larvae in field (larvae/grass clump)
HERB	Julian date grass herbicide is applied
JINSECT	Array of julian dates that insecticide is applied
TCOST	Cost of each insecticide application ($/acre)
PRICE	Market price of corn ($/bu)

Model Outputs

After all input data are entered, a graph of the proportion of the stalk borer population that has hatched and moved into the corn for Julian days 100 to 200 is displayed on screen. If the yield portion of the model has been selected, the display also will include the Julian dates for corn developmental stages V1, V4, and V7 (Ritchie et al. 1986). At this point, the dates for up to 3 insecticide applications can be entered. Each run simulates stalk borer injury and grain yield for a no-insecticide program and for the user-specified insecticide program. If a noncrop area was included in the simulation, yields are predicted by row (bu/acre) for the 8 rows closest to the noncrop area. In the instance where no noncrop area is present, yields are predicted for the specified area of the field. At the end of each simulation, output is printed which contains a listing of all input parameters, data for stalk borer development and movement, and daily predictions of crop stage and number of larvae attacking corn. The program prints the expected percentage of plants injured and yield predictions, by row, for programs with and without insecticides. Finally, the cost effectiveness of the insecticide program is determined. Table 12 contains a complete listing of output variables.

Model Equations and Parameters

Degree-day Calculations

Centigrade degree days (CDD) for predicting stalk borer phenology and corn development are computed from daily minimum and maximum temperatures by using a 0.5-day sine wave algorithm developed by Higley et al. (1986). Degree days for stalk borer development and movement are

Table 12. Model output at the completion of each simulation. A listing of input variables (Table 11) is included in the output

Variable name	Description
SAMP1, SAMP2	Julian dates for optimal sampling of grass to estimate larval densities (500-600 CDD)
CDDSB, FDDSB	Degree day accumulations (1 April to 31 July) for stalk borer development, ^{o}C and ^{o}F
PHATCH	Proportion of population that hatched (1 April-31 July)
PMOVE	Proportion of the larvae that moved out of noncrop areas (1 April-31 July)
FMOVE	Proportion of larvae moving from grass in the field after herbicide is applied (1 April-31 July)
NSBG	Larvae in noncrop areas before movement begins
NSBF	Larvae in field grasses before movement begins
CDDC, FDDC	Degree day accumulations (planting to 31 July) for corn development, ^{o}C and ^{o}F
CSTAGE	Corn growth stage as predicted by degree day model (planting to 31 July)
N	Number of larvae that survived to attack corn on each date (planting to 31 July)
DAM	Percentage of damaged plants in each row for programs with and without insecticide use
PREDYLD	Yield (bu/acre) for each row for programs with and without insecticide
ACRES	Crop area (acres) for each simulation
DIFYLD	Yield difference between programs with and without insecticide (averaged across rows)
TCOST	Cost of insecticide program
RETURNS	Difference between cost of insecticide program and value of additional yield

accumulated from 1 January and use a developmental threshold of 5.1°C (Levine 1983). Minimum and maximum temperature thresholds of 10 and 30°C, respectively, are used to calculate degree days for corn development (Gilmore and Rodgers 1958), which are accumulated from planting until 31 July.

Egg Hatch

The subroutine BORER determines the cumulative proportion of eggs that hatch (PHATCH) on each day (I) as a function of stalk borer degree days (CDDSB(I)) by using the logistic equations described by Lasack et al. (1987) for the appearance of first instars in the field. If April rainfall is less than or equal to 10 cm, Equation 1 is used. Otherwise, Equation 2 is used. Daily proportion of hatch is calculated as the difference between PHATCH(I) and PHATCH(I-1).

$$\mathrm{PHATCH(I)} = (1 + \mathrm{EXP}(9.95 - 0.0292\ \mathrm{CDDSB(I)}))^{-1} \qquad (1)$$

$$\mathrm{PHATCH(I)} = (1 + \mathrm{EXP}(16.8 - 0.0417\ \mathrm{CDDSB(I)}))^{-1} \qquad (2)$$

Movement

Subroutine BORER also calculates the cumulative proportion of the larval population that moves (PMOVE(I)) from noncrop areas into the corn field for each day (Equation 3). This equation is a function of degree days and was based upon pitfall trap captures of larvae moving out of smooth brome (*Bromus inermis* Leyserra) (see Section VI). Daily proportion of movement is calculated as the difference between PMOVE(I) and PMOVE(I-1).

$$PMOVE(I) = (1 + EXP(X(I)))^{-1} \quad \text{where} \tag{3}$$

$$X(I) = 26.091 - 0.0529CDDSB(I) + 3.4E\text{-}5(CDDSB(I))^2 \; 8.3E\text{-}9(CDDSB(I))^3$$

In no-tillage situations, eggs may be laid on grasses present within the field itself (Stinner et al. 1984). Typical farming practices include the application of a herbicide, such as paraquat, to control grasses. A second movement equation was developed to describe movement of larvae out of grasses present within the field and is a function of the number of days after a grass herbicide was applied (Equation 4). The cumulative proportion of larvae moving (FMOVE(I)) was calculated by integrating a chi-square density function with a mean of 6. A 1-day lag period was incorporated into the function to allow for the herbicide to begin to kill the grass. This equation predicts that maximum movement occurs 4-6 days after herbicide application and that most larvae move out of the grass by the end of 2 weeks.

$$FMOVE(I) = 1 - EXP(-T)\ (1 + T + T^2/2) \tag{4}$$

In Equation (4), $T = (I - HERB - 1)/2$ and HERB is the Julian date that the herbicide was applied.

Survival

Life table studies of natural stalk borer populations have shown that most mortality occurs when stalk borers are searching for a second host. Lasack et al. (1987) reported that mortality rates of fourth and fifth instars were as high as 78% and 93% in populations sampled in 1984 and 1985, respectively. Mortality attributed to parasitoids accounted for less than 5% in that study. Once stalk borer larvae tunnel into a host plant, overall mortality appears to be very low since survival rates for larval stages 1 to 3 were 80% or higher. However, Lasack et al. (1987) suspected that heavy rains occurring after hatch but before larvae tunnelled into a grass host caused a substantial reduction in populations.

In an effort to incorporate survival information into the model, survival of small larvae before entering grass stems was assumed to be a function of rainfall. We assumed mortality rates for young larvae of 20, 50, and 80% for daily rainfall of <0.5, <1.5, and ≥1.5 cm, respectively. To simplify the model, we assumed that mortality of young larvae occurred only on the day that the larvae eclosed. If the user inputs estimated densities of larvae after 500-600 CDD have accumulated, additional mortality from rainfall is assumed to be zero. We also assumed that 50% of the larvae that moved from grass would die before significant feeding had occurred. This value was selected because small-plot infestation trials averaged 50-70% of the plants injured when infested at a rate of 1 larva per plant (see Section II). However, if seedling corn is not present in the field on the day when larvae are moving out of the grass, larval survival is assumed to decline linearly from 100% to 0% over a 5-day period. Reports from Illinois indicate that stalk borer larvae can survive at least 5 days within the field before the crop has emerged (Illinois Natural History Survey 1986).

Survival during movement also is a function of insecticide efficacy. The model expresses insecticide efficacy as a function of the number of days after the date of application. Although complete efficacy data are unavailable, findings from insecticide trials, in which stalk borers were placed in plots on the same day as the insecticide was applied, showed that the number of injured plants was reduced to 17% (Bailey et al. 1985) and 31% (unpublished data) in plots with fenvalerate (112 g ai/ha) compared to unsprayed plots. Consequently, we assumed apparent survival rates of 20, 40, 70, and 100% for 0-3, 4-7, 8-12, and >12 d after an insecticide was applied, respectively. Taking into consideration that 50% mortality was assumed in unsprayed plots, the adjusted survival rates were calculated as 10, 20, 35, and 50% for 0-3, 4-7, 8-12, and >12 d after application, respectively.

Distribution of Larvae

When stalk borers move from noncrop areas into corn, typically the rows that are closest to the grass sustain the highest percentage of plants injured. Very little movement occurs beyond 8 rows (Levine et al. 1984). Bailey (1985) found that the mean number of larvae in a row was inversely related to row position. For our purposes, Bailey's equation was modified to predict the proportion of larvae that move into a row. Consequently, the total number of larvae (N) which move into a row (J) on a given date (I) is given by Equation (5). NG(I) is the number of larvae that are moving out of noncrop areas on each day and NF(I) is the number of larvae that move out of grasses within the field.

$$N(I,J) = NG(I)\ (-0.0308 + 0.4402/J) + NF(I)/8 \qquad (5)$$

Within a row, stalk borer larvae tend to assume a regular distribution (Davis and Pedigo 1989). In low to moderate stalk borer densities, usually only one larva will infest each plant. However, if populations in the grass are high (>1 larva/930 cm^2), multiple larvae can attack each plant, resulting in a slightly clumped dispersion pattern. The model uses Equations 6 and 7 to predict the number of new plants attacked on each day (ATTACK). HEALTHY(J) is the number of uninjured plants remaining in each row. On the day that plants emerge, DELAY is equal to the number of larvae that survived during the previous five-day period. Otherwise DELAY equals 0.

$$\text{ATTACK} = \text{HEALTHY(J) for N(I,J) + DELAY} > \text{HEALTHY(J)} \quad (6)$$

$$= \text{N(I,J) + DELAY for N(I,J) + DELAY} \leq \text{(HEALTHY(J))} \quad (7)$$

Corn Development

Stage of corn development (CSTAGE) was calculated daily in the subroutine CGROW as a function of degree days accumulated after planting (Neild and Seeley 1977) (Equation 8). The rate of development (SLOPE) is adjusted for growing degree days (^oF) needed for corn to reach maturity (MDD) (Equation 9). If the the user indicates that soil moisture at planting is not sufficient for germination, degree-day accumulations are delayed until rainfall exceeds 0.5 cm for a single day.

$$\text{CSTAGE(I)} = -0.31 + \text{(SLOPE)(CDDC(I))}\ 9/5 \quad (8)$$

$$\text{where SLOPE} = (1/125.5) - 1.533\text{E-}6\text{(MDD)} \quad (9)$$

Yield Loss

Severity of injury to plants infested by stalk borers varies according to stage of corn development (see Section III) In Sections II and III, injury was classified by using a 6-class scale which ranged from 1 (uninjured) to 6 (killed). Injury profiles were developed to reflect the proportion of plants in injury classes 2 to 6 for developmental stages ranging from 1- to 7-leaf (see Section III). An injury-profile matrix of proportions is incorporated into SBMGMT and used to calculated the number of plants that fall into each injury class for each row and day. The yield-loss program, described and validated in Section IV, is incorporated into SBMGMT as two functions, YIELD and YLOSS. Individual plant yield (Y) is a function of individual injury rating (RATE), average injury rating for each corn row (AR), and moisture-stress condition. If accumulated rainfall from 1 April to 1 July is less than 15 cm, then drought-stress conditions are assumed (Equation 10). Otherwise moisture is assumed to be adequate for normal crop development (Equation 11). Information on injury and individual plant yield is combined to predict total yield for each row.

Drought conditions: $Y = 0.997 - 0.265\ (RATE) + 0.162\ (AR) \qquad (10)$

Adequate moisture: $Y = 0.919 - 0.0397\ (RATE)^2 + 0.113\ (AR) \qquad (11)$

RESULTS AND DISCUSSION

Model Validation

Simulation runs, using weather data from 1984-1989, indicate that SBMGMT gives reasonable predictions for egg hatch, optimal sampling dates, and movement of larvae (Table 13). Weather data used in the simulations were obtained from the National Oceanic and Atmospheric Administration weather stations located in Newton, IA (1984-1987) and Ames, IA (1988-1989). As reported earlier, the yield-loss component of the model was validated in Section IV.

To further evaluate model predictions, model output was compared with data collected during 1985 from two locations within a field near Baxter, Iowa (Jasper County). Each data set included information on larval densities in grass, number of larvae recovered from weekly samples of corn, percentage of the plants damaged by stalk borers, and yield estimates for the three rows nearest to a smooth brome terrace. Although data from this field were included in the data set which was used to develop regression models for egg hatch and larval movement, these data sets are valuable to evaluate estimates of crop development, stalk borer survival, distribution of damage, and yield predictions.

Estimates of stalk borer densities in grass, taken before movement began, indicated initial densities of 4.0 larvae/ft^2 and 0.29 larva/ft^2 at locations A and B, respectively.

Model predictions of the number of larvae that attacked corn plants in each row paralleled observations of average number of larvae recovered during the period from 30 April to 18 July (Figure 17). There

Table 13. Comparision of model predictions of egg hatch, sampling dates, and movement with observed ages of stalk borers (indicated by mean larval stage) collected from grass samples during 1984-1989 in central Iowa

	Hatch		Sampling dates		Movement	
Year	Predicted	Actual	Predicted	Actual	Predicted	Actual
1984	19-30 May	23 May: 1.03 30 May: 1.17	2-8 Jun	6 Jun: 2.14	16 Jun-9 Jul	20 Jun: 4.68 2 Jul: 5.58
1985	19 Apr-6 May	23 Apr: 1.00 7 May: 1.92	12-21 May	13 May: 2.57 20 May: 3.20	31 May-26 Jun	3 Jun: 4.42 26 Jun: 6.00
1986	21 Apr-6 May	2 May: 1.00	12-21 May	20 May: 2.70	1 Jun-22 Jun	2 Jun: 3.71 19 Jun: 5.33
1987	16 Apr-2 May	27 Apr: 1.55 5 May: 1.69	9-15 May	13 May: 2.55	24 May-15 Jun	1 Jun: 3.99 15 Jun: 5.45
1988	29 Apr-11 May	NA	16-23 May	NA	31 May-21 Jun	7 Jun: 4.17
1989	27 Apr-15 May	NA	21-29 May	22 May: 2.95 25 May: 3.11	7 Jun-2 Jul	NA

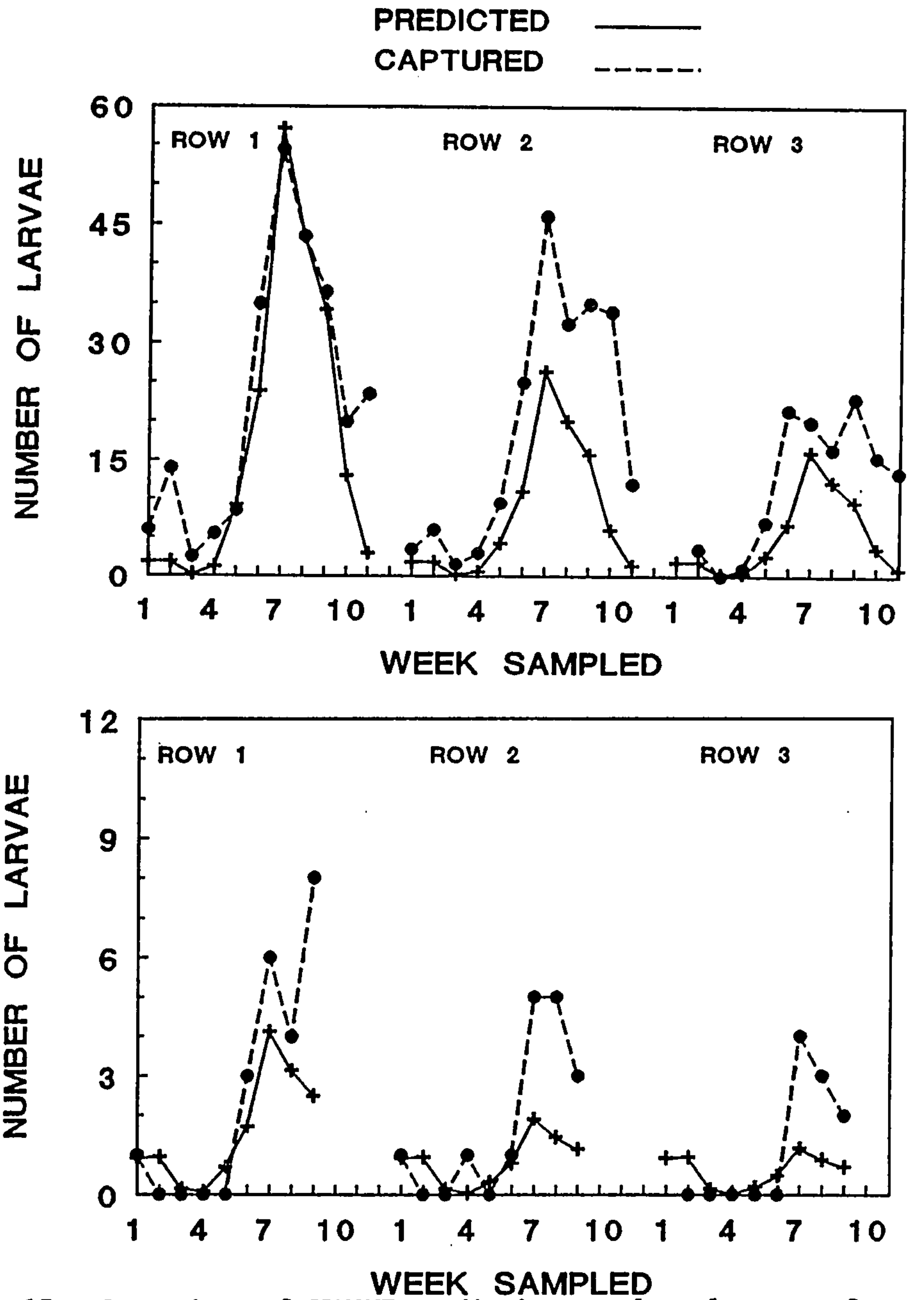


Figure 17. Comparison of SBMGMT predictions to larval counts from samples of corn collected at two locations near Baxter, Iowa in 1985. Model predictions represent the number of migrating larvae that would attack corn plants from one sampling date to the next. Row 1 is closest to the grass terrace. Top: 4 larvae/ft^2 in terrace. Bottom: 0.29 larva/ft^2 in terrace

was a tendency for the number of captured larvae to be greater than the predicted number moving during the sample period. This may be partially caused by survival of larvae from one sampling period to the next.

In general, SBMGMT performed better at low stalk borer populations than at high populations. Model predictions overestimated the percentage of plants damaged by stalk borers at location A, especially in row three (Figure 18). However, estimates for location B were very similar to field observations. The model assumes that invading stalk borers will initially attack only uninfested plants. Relaxing this assumption may improve predictions in future versions of SBMGMT.

Although predicted damage for rows one and two were relatively similar to observed damage for location A, actual yield was much lower than predicted (Figure 18). Yield loss equations in the model were based on a maximum of one larvae per plant. At peak movement, plants averaged over 1.5 larvae per plant. This suggests that the assumed injury profiles used by the model may not adequately reflect the severity of injury for extremely high stalk borer populations. In contrast, the model was reasonably accurate in predicting grain yields for location B.

Model Testing

Planting Date

The effectiveness of various cultural strategies and pesticide programs in reducing injury and yield loss from stalk borers was evaluated in simulation runs of SBMGMT. For all simulations, the yield

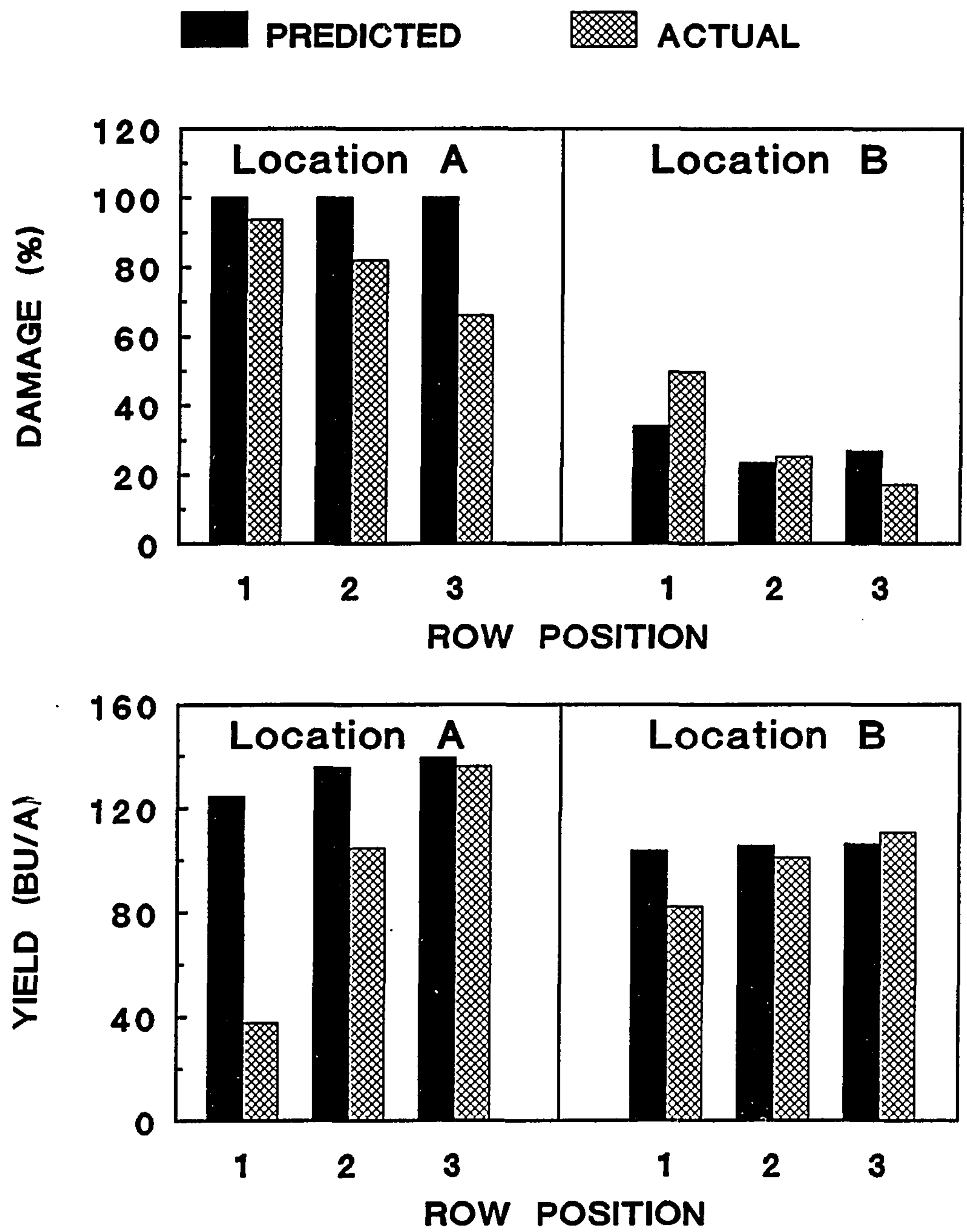


Figure 18. Comparison of SBMGMT predictions of percentage of plants damaged (top) and grain yield (bottom) to field data collected at two locations near Baxter, Iowa in 1985. Initial stalk borer populations were 4.0 and 0.29 larvae/ft^2 at locations A and B, respectively

potential was assumed at 150 bu/a (94.3 q/ha). In situations where grassy, noncrop areas are present, simulations predicted that early planting reduces the susceptibility of corn to stalk borer injury (Figure 19). However, the magnitude of the yield loss depends upon stalk borer density and weather regime. Cool spring temperatures, such as in 1984 in central Iowa, slow stalk borer development and movement relative to corn development. Thus, corn is less vulnerable to severe injury from migrating larvae. Warm spring temperatures, such as in 1986, increase the susceptibility of the crop to injury. However, planting early has the potential to reduce yield losses by as much as 18 bu/a (11.3 q/ha) (Julian date 125 vs 145, 2.0 larvae/ft^2 in noncrop areas). Although not shown in Figure 16, results of simulation runs, which used central Iowa weather data for 1985 and 1987, paralleled the 1986 results. In contrast, moisture stress increases the susceptibility of older plants to injury and reduces the effectiveness of early planting (1988 weather data).

Plant Population

A second series of simulations evaluated the effect of plant population on yield in stalk borer-infested fields (Figure 20). One assumption in these simulations is that plant population does not alter the yield potential of the field. Fields with higher plant populations tend to tolerate more injury than fields with low populations. This effect increases as stalk borer density increases. For example, at densities of 0.5 larva/ft^2 in grassy areas, yields increase ca. 0.5 bu for each 1000-plant increase in plant population. At 2.0 larvae/ft^2, the rate of increase in yields rises to ca. 1 bu per 1000 plants.

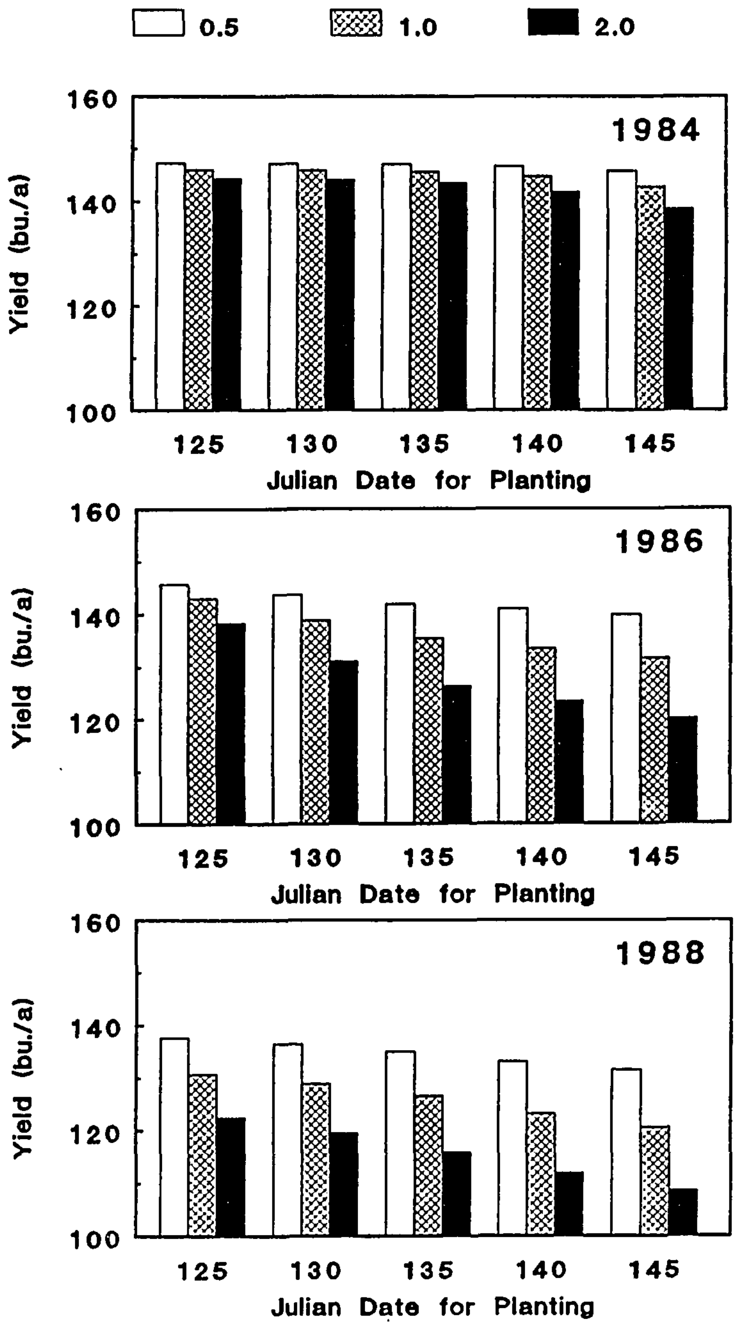


Figure 19. Effect of planting date and larval density (0.5, 1.0, and 2.0 larvae/ft^2) on average grain yield in eight rows adjacent to noncropped area. Simulations used weather data from 1984, 1986, and 1988

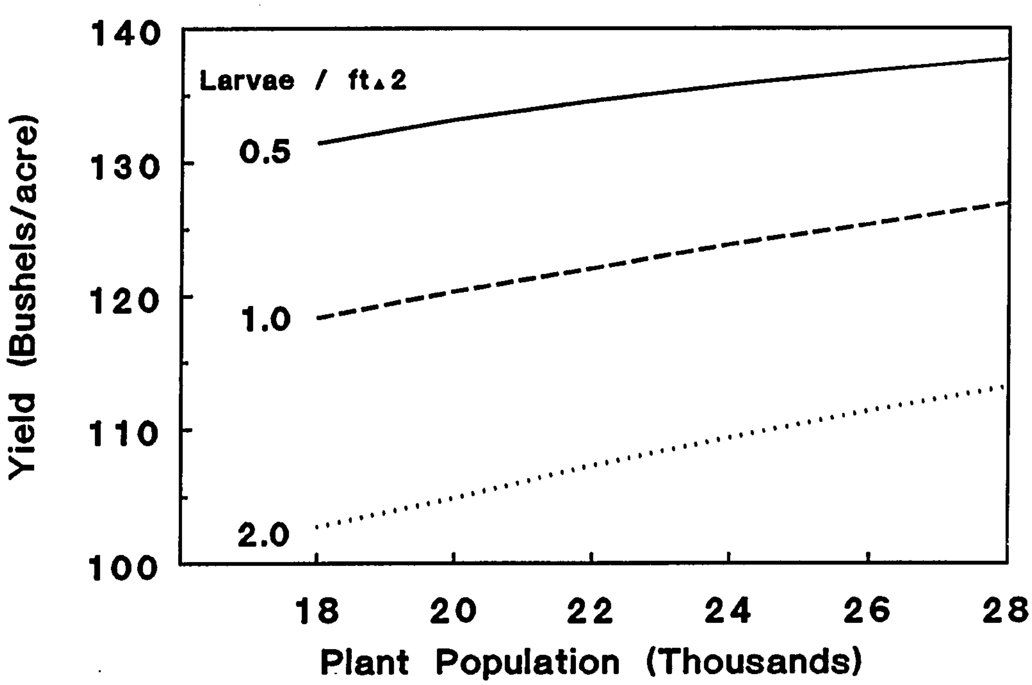


Figure 20. Simulated effect of plant population on average grain yield in four rows adjacent to noncropped area

Herbicide Applications

In no-tillage systems, herbicide application is the major strategy for control of perennial grasses. A series of simulations were run to predict the effectiveness of timing of herbicide application relative to planting date for two weather regimes (1984 and 1986) (Figure 21). If stalk borer egg hatch occurs after planting, such as was the case in 1984, varying the herbicide application by as much as 15 days had little effect on the incidence of injury. In this situation, newly-emerged larvae are assumed to attack seedling corn without first feeding on grasses. These predictions are supported by observations of Lasack and Pedigo (1986) who found first instars feeding in spike stage and 1-leaf corn plants. However, if larvae are present in field grasses when herbicides are applied, injury is lessened if application precedes planting. These predictions paralleled reports from researchers in Illinois that the absence of spring weed growth significantly decreased the resulting infestations of larvae (Illinois Natural History Survey Reports, 1986).

Insecticide Application

In terraced situations, timing of insecticide application altered net returns, as measured by the difference in crop value with and without herbicide, minus the cost of control (Figure 22). Single- and double-spray applications, applied to either four rows or eight rows nearest the noncrop areas, also were evaluated for larval densities of 1.0 and 2.0 larvae/ft^2. Because stalk borer populations decline rapidly with distance from grassy areas, insecticide applications to rows five through eight usually are not cost effective. In fact, net returns are

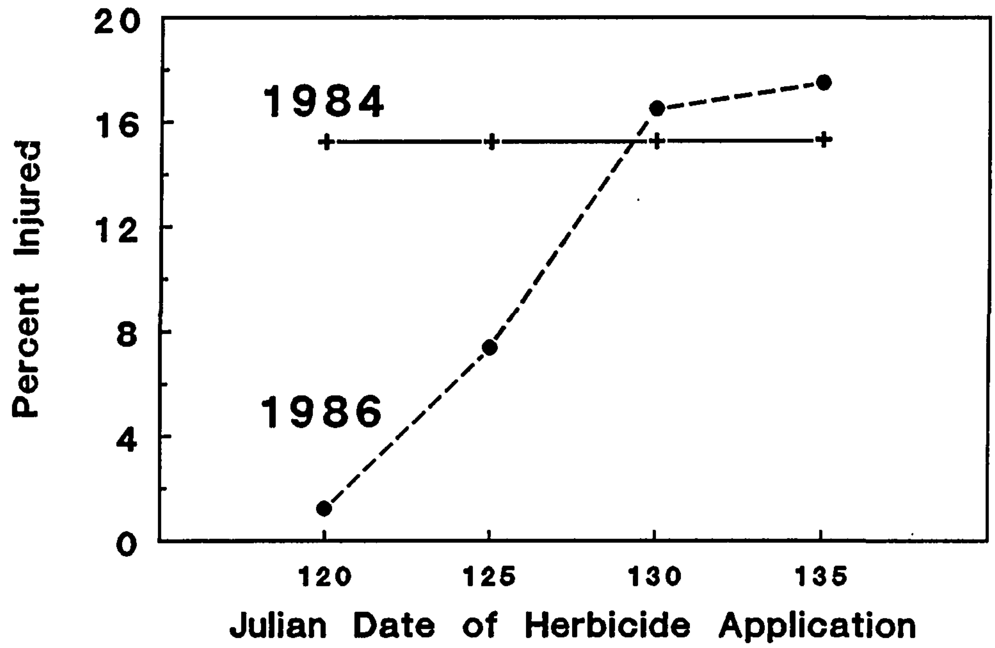


Figure 21. Percentage of injured plants in no-tillage fields for various herbicide application dates. For each simulation, the Julian date for planting was day 130

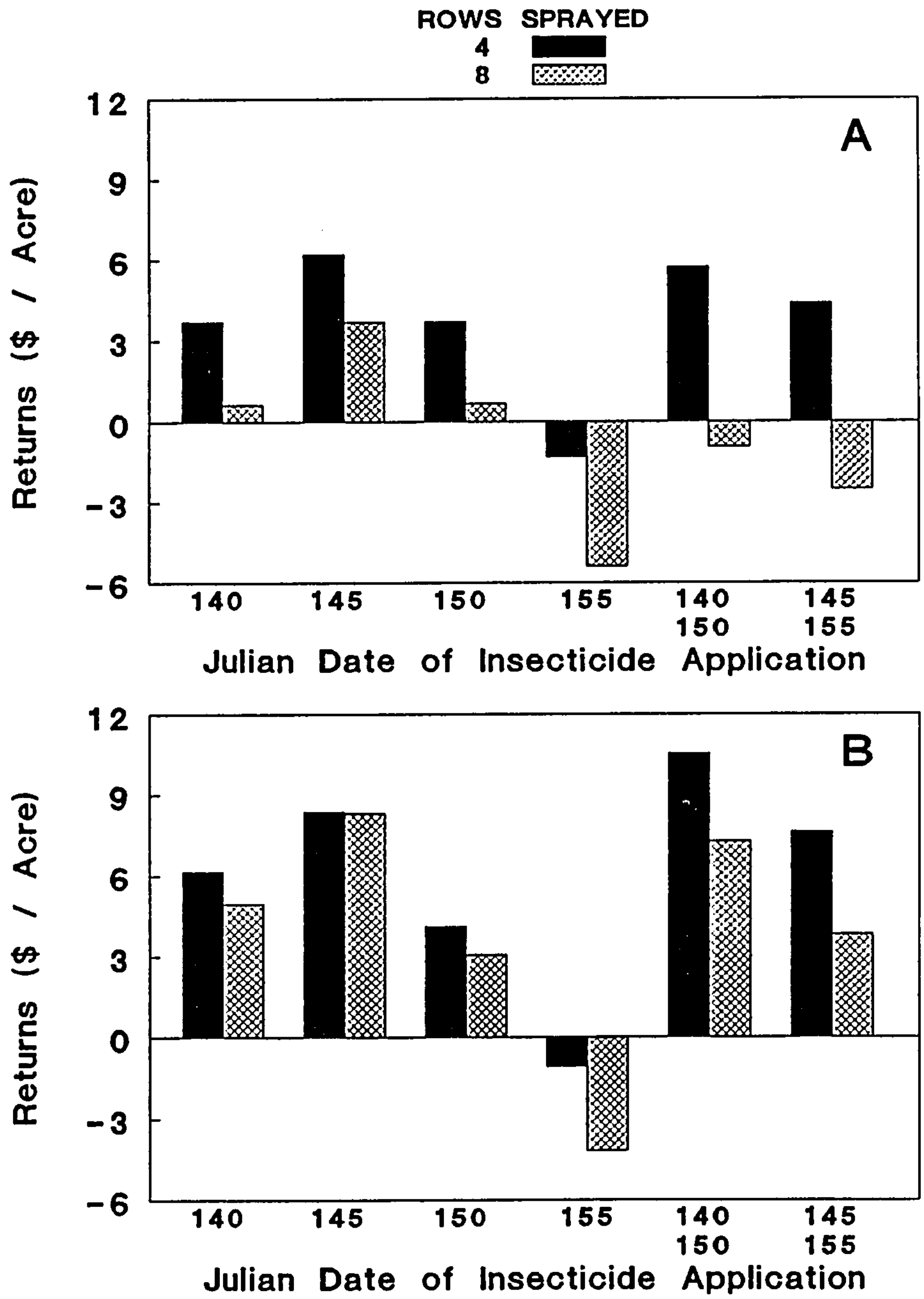


Figure 22. Effects of insecticide application date and area of field sprayed on monetary returns. In each simulation, corn was assumed to be planted on Julian date 130 (1987 weather data). A. 1 larva/ft^2. B. 2 larvae/ft^2

higher if two applications to rows one through four are made compared to a single application to all eight rows. Finally, SBMGMT predicts that applications early in the movement period are more effective in reducing yield loss, even though the overall infestation level may not be reduced. Because of the differential susceptibility of young seedlings to stalk borer injury, early applications generally are more effective.

The results of these simulations require further field research to validate the predictions and to test assumptions incorporated into *SBMGMT*. Particularly, additional research is needed to evaluate the assumptions on stalk borer survival after pesticides have been applied. However, the model can be a useful tool in planning management strategies to reduce the crops susceptibility to injury from stalk borers.

SUMMARY AND CONCLUSIONS

The results of this reseach have provided valuable information on the relationships between timing of stalk borer injury and yield. The effects of stalk borer injury, imposed at corn leaf stages 1 through 7, on visible injury, stalk elongation, and grain yield was evaluated in a three-year study. Tunneling by stalk borer in seven-leaf corn was confined to the lower nine internodes. The distribution of stalk borer tunnels showed little overlap with the distribution of European corn borer (Ostrinia nubilalis (Hübner)) tunnels. A fifth-instar stalk borer that survives to pupation would be expected to produce a tunnel 15.8 cm long. Although tunneling shortens internodes at and above the tunnel, yield loss varied by year. In years with adequate moisture (1986 and 1987), Pioneer hybrids 3541 and 3377 were able to tolerate tunneling without any significant plot yield reductions detected. However, when moisture was not adequate, as in 1988, yields were significantly reduced.

A six-class scale was developed to evaluate injury in seedling corn attacked by stalk borer. The average injury rating for a plot declined 0.332 $\pm$ 0.033 points per leaf stage. In years of adequate rainfall, yields declined linearly as plants were attacked later in development. Injury profiles were developed to describe feeding injury. Plot yield losses seem to be moderated by the ability of uninfested or slightly injured plants to compensate for severe stalk borer injury. Relatively healthy plants were able to increase yield by 5-50% above the average plant yield observed in uninfested plots. Subsequently, regression models were developed to predict plot yield and individual plant yield. Models for individual plant yield were combined with injury profiles to predict grain yield as a function of percentage of plants injured and corn development stage.

Economic injury levels (EILs) and economic thresholds were determined and a management program, which incorporated sampling stalk borer densities in grass, was presented. In years with adequate moisture available for crop development, the EIL for stalk borer ranges from 15 to 50% for corn attacked at leaf stages one through six. Under these conditions, infestions in 7-leaf corn are not economical. In contrast, drought conditions tend to reduce the EILs, particularly the EILs for older corn.

In a second study, degree-day models were used to time insecticide applications (permethrin) to egg hatch and larval movement. Although applications at egg hatch significantly reduced stalk borer density in grass terraces by 54-85%, applications timed with movement were more effective in reducing severe damage to corn.

Finally, a management model, SBMGMT, was developed to simulate the stalk borer/corn agroecosystem. Information available in the literature was combined with models developed from the previously described research. SBMGMT predicts stalk borer phenology, corn development, and grain yield for various management strategies. Simulation runs indicated that cultural practices such as planting date, date of herbicide application, and plant population, could alter severity of plant injury and subsequent yield losses. Additional simulation indicated that in terraced fields, application of insecticide is seldom profitable when applied to rows five through eight. In general, insecticides are more effective in reducing yield losses if the applications coincide with early corn growth stages and stalk borer larvae are migrating. However, additional research is needed to test model assumptions, particularly those assumptions related to stalk borer survival after pesticides are applied.

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APPENDIX:

SBMGMT Program

```
'***********************************************************************
'
'      *****A Program to Predict Yield Losses from Stalk Borer*****
'                             Version 1.0
'
'                        Written by Paula M. Davis
'                             March, 1990
'
'--Variable List--
'
'A             Real, factor used in sine wave calculation
'Acres         Real, dimensions in acres of crop area
'Attack        Real, Number of plants attacked by stalk borer
'An1$          Character, indicates if grassy areas are present
'An2$          Character, indicates if a herbicide was applied
'An3$          Character, indicates if an insecticide was applied
'An4$-An6$     Character, print out selection
'Ans$          Character, answer for question
'AppN          Real, number of insecticide applications
'Ar#           Double precision real, average injury rating of the field
'Arain         Real, April rainfall total
'Array1-Array3 Real, arrays used in graph routine for labels
'Avgw(214,4)   Real, temporary array for average weather data
'Cddc(214)     Real, degree day accumulations (centigrade) for corn
'Cddsb(214)    Real, degree day accumulations (centigrade) for stalk
'              borer
'Cha$          Character, indicator for changing parameter settings
'Change        Real, menu selection for parameter settings
'Convert       Real, function for converting temperature and rainfall
'              data
'Cost          Real, insecticide costs, $/acre
'Cstage(214)   Real, corn development, -.31 to 10 scale
'Cweath(214,4)  Real, temporary array for current weather data
'D$            Character, Choice for stalk borer density in grassy areas
'D             Real, indicator for days
'Daml          Real, percentage of plants damaged in a row
'Damyld#       Double precision, yield contribution of injured plants
'Dat           Real, dummy variable for weather data
'Dayl%, DayL%  Integer, first and last julian day that current weather
'              data
'              is available
'Dday          Real, CDD for the day
'Dead#         Double precision, proportion of first instars that die
'              each day
'Degday#       Double precision, function for calculating degree day
'              accumulations
'Delay         Real, # of larvae that survive during a 5-day period before
'              corn has emerged.
'Dg$           Character, choice for stalk borer density in grass clumps
'Difyld        Real, average difference in yield (bu/a) between treated
'              and untreated areas.
```

```
'Dmax, Dmin    Real, Developmental maximum and minimum temperatures
'F1, F2        Real, dummy variable for number of stalk borer in field
'Fddc(214)     Real, fahrenheit degree day accumulations for corn
'Fddsb(214)    Real, fahrenheit degree day accumulations for stalk borer
'Fdif#         Double precision, proportion of population that moves from
'              noncrop areas on a given day
'Flength       Real, field length in feet
'FM#           Double precision, cumulative movement out of grass as a
'              function of days after herbicide was applied
'Fmove#(214)   Double precision, proportion of larvae moving from grass
'              clumps following a herbicide application
'Ftime$        Character, date stalk borer density estimates in field
'              were made
'Fwidth        Real, field width in feet
'GC            Real, average number of grass clumps per yard of row
'Gdif#         Double precision, proportion of population that moves from
'              noncrop areas on the current day
'GrassN        Real, number of grass clumps in the field
'Grow!(26,2)   Real, corn growth stages input from GROWTH.DAT file
'Gtime$        Character, date stalk borer density estimates in grassy
'              areas were made
'Healthy(2,8)  Real, number of uninjured plants within each row
'Herb%         Integer, julian day that herbicide was applied
'Hsine(2)      Real, half-day sine wave degree-day accumulation
'Hyld#         Double precision, yield contribution of healthy plants
'I             Integer, loop indicator variable
'Injury(7,5)   Real, proportion of plants in each injury rating class
'              for a given stage of development
'Injplt(2,8,7,5)  Real, proportion of plants within a row that have
'              been injured by stalk borer for each leaf stage and injury
'              rating
'J             Real, loop indicator variable
'JIN           Real, indicator for untreated (1) vs sprayed (2) simulation
'              run
'Jinsect%(3,2)  Real, dates of insecticide application & rows sprayed
'Jplant        Integer, julian date that corn was planted
'L             Integer, loop indicator for leaf stage
'Leaf%         Integer, dummy variable for leaf stage
'Leaf%(I)      Integer, leaf stage of the corn
'Leap          Real, additional day for a leap year
'Low           Real, dummy variable used in Surv function
'M1            Integer, selection variable for degree day calculation
'Mday          Integer, maximum number of days used in the simulation
'Mdd!          Real, fahrenheit degree days for corn to reach maturity
'Menu          Integer, menu selection variable
'Mort          Real, proportion of larvae that die from rain
'M             Real, maximum days in the simulation minus 1
'MT            Real, mean daily temperature
'N(2,213,8)    Real, number of larvae within each row
'N1, N2        Real, julian day for April 1 and July 1
'Name1$        Character, name of file containing current weather data
```

```
'Name2$         Character, name of file containing 20-year average weather
'               data
'Nrow           Integer, indicator of row within the field
'Nrun           Real, indicator of number of simulations run
'Nsbfl!         Real, low and high number of larvae in the field
'Nsbgl!         Real, low and high number of larvae in the grass
'P1, P2         Real, used in calculating sinewave accumulation
'PH#            Double precision, cumulative proportion of eggs that
'               hatched 2 days after herbicide was applied
'Phatch#(214)   Double precision, cumulative proportion of stalk borers
'               hatching each day
'Pinj#          Double precision, proportion of plants injured
'Pmove#(214)    Double precision, proportion of larvae moving from grassy
'               areas
'Potyld         Real, yield potential of field, bu/acre
'Ppop           Real, plant population per acre
'Ppopr          Real, number of plants within a row (terrace situation) or
'               field (no grassy area present)
'Predyld(2,8)   Real, yield in bu/acre for each row
'Pscale$        Character scale for rainfal data in Convert function
'Pscale1$       Character, scale for current rainfall data
'Pscale2$       Character, scale for 20-year average rainfall data
'R%             Integer, loop indicator for injury rating
'Rain           Real, accumulated rainfall from April 1 to July 1
'Rate%          Integer, injury rating of a plant
'Remain         Real, used in determining a leap year
'Returns        Real, Difference between additional crop value and
'               insecticide program costs ($/specified area)
'RowNf#         Double precision, number of larvae that moved from grasses
'               present in the field to each row of corn on a given day
'RowNg#         Double precision, number of larvae that moved from noncrop
'               areas into each row on a given date
'Rwidth         Real, row width in inches
'S(3)           Real, survival coefficients after insecticide treatments
'S1%, S2%       Integer, dummy variable (toggle)
'Samp1%, Samp2% Integer, julian days to best sample for stalk borers in
'               grass
'Sbfl           Real, low and high number of stalk borers in field, per
'               grass clump
'Sbgl           Real, low and high number of stalk borers in grass, per
'               ft^2
'SBorC          Real, dummay variable to indicate either stalk borer or
'               corn
'Search%        Integer, function for determing corn leaf stage
'Slope#         Double precision, adjustment for maturity class of corn
'Soil$          Character, indicates if initial moisture condition was
'               adequate
'               for germination
'Stage          Real, variable in function Search to indicate corn growth
'               stage
'Stress         Real, indicator of drought stress or adequate moisture
```

```
'Surv          Real, function for determining stalk borer survival
'Survive       Real, proportion of stalk borers that survive to attack a
'              plant
'T             Real, factor used in calculating movement after a herbicide
'              was applied.
'T1, T2        Real, variables used in calculating degree days
'Tcost         Real, cost of insecticide program ($/specified area)
'Tlength       Real, terrace length in feet
'Tmax          Real, maximum temperature for the day
'Tmin(2)       Real, minimum temperatures for the day
'Totsb(2,213) Real, total stalk borers that can attack corn plants within
'              the field on a given day
'Tpinj#        Double precision, total plants injured by stalk borers
'Tscale$       Character, temperature scale in convert subroutine
'Tscale1$      Character, temperature scale (C or F) for current weather
'              data
'Tscale2$      Character, temperature scale (C or F) for 20-year average
'              weather data
'Twidth        Real, terrace width in feet
'Value         Real, value of additional crop yields as a result of
'              insecticide applications ($/specified area)
'Weather(214,4) Real, julian day, max and min temperatures, and rainfall
'X1, X2        Real, used in calculating sine wave degree days
'Y#            Double precision, dummy variable used in calculating yield
'Y1#           Double precision, exponent for hatch function
'Y2#           Double precision, exponent for movement function
'Year          Integer, year of simulation
'Yield#        Double precision, function for calculating grain yield
'Yloss#        Double precision, function for calculating individual
'              plant yield
'
'*************************************************************************
DECLARE SUB FileIn (Dayl%, DAYL%, Mday!, Name1$, Name2$)
DECLARE SUB Borer (Mday!, Samp1%, Samp2%, Herb%)
DECLARE SUB Print1 (Name1$, Name2$)
DECLARE SUB Cgrow (Mday!, Jplant!, Mdd!, Soil$, Stress!)
DECLARE SUB Print2 (Nrow, Ppopr)
DECLARE SUB Instruct ()
DECLARE SUB Graph (Menu, Jinsect%())
DECLARE FUNCTION Convert! (Dat!, J!, Tscale$, Pscale$)
DECLARE FUNCTION Degday# (SBorC!, Tmin!(), Tmax!)
DECLARE FUNCTION Search% (Stage!)
DECLARE FUNCTION Surv! (I!, J!, Jinsect%())
DECLARE FUNCTION Yield# (JIN!, J!, Stress!, Potyld!)
DECLARE FUNCTION Yloss# (Rate%, Ar#, Stress!)
'
'                         INITIALIZE VARIABLES
'
OPTION BASE 1
DIM Mort, Injplt(2, 8, 7, 2 TO 6) AS SINGLE
DIM Leaf%(214), GROW!(26, 2)
```

```
DIM SBorC, Year  AS INTEGER, Jinsect%(3, 2)
DIM weather(214, 4), Healthy(2, 8), N(2, 213, 8) AS SINGLE
DIM Injury(1 TO 7, 2 TO 6), PredYld(2, 8) AS SINGLE
DIM Fddsb(214), Cddsb(214), Fddc(214), Cddc(214), Cstage(214) AS SINGLE
DIM Phatch#(214), Pmove#(214), Fmove#(214), TotSb(2, 213)
SCREEN 8
COLOR 7, 1
Nrun = 1
KEY(1) ON          'TRAP F1 KEY FOR INFO ON JULIAN DAYS
ON KEY(1) GOSUB Julian
KEY 1, "Julian"
CLS 2: PRINT : PRINT : PRINT
PRINT SPC(15); "SBMGMT - A MANAGEMENT MODEL FOR STALK BORER IN CORN"
PRINT : PRINT SPC(27); "Developed by Paula M. Davis"
PRINT : PRINT SPC(30); "Iowa State University"
PRINT : PRINT SPC(30); "      March 1990"
'
OpeningMenu:
'
IF Nrun > 1 THEN CLS 2
PRINT : PRINT : PRINT SPC(30); "OPENING MENU"
PRINT
PRINT SPC(25); "1.  INSTRUCTIONS"
PRINT SPC(25); "2.  STALK BORER DEVELOPMENT"
PRINT SPC(25); "3.  YIELD MODEL"
PRINT SPC(25); "4.  EXIT PROGRAM"
PRINT : INPUT ; "           Enter selection from menu: ", Menu
SELECT CASE Menu
'
CASE 1                 'GENERAL INSTRUCTIONS
'
   CALL Instruct
   GOTO OpeningMenu
'
CASE 2                 'STALK BORER DEVELOPMENT
'
   CLS 2: PRINT : PRINT : PRINT
PRINT SPC(10); "Selection 2, stalk borer development, predicts egg hatch"
PRINT SPC(10); "and movement of larvae from grassy areas to corn.  These"
PRINT SPC(10); "predictions use daily minimum and maximum temperatures"
PRINT SPC(10); "and rainfall amounts.  The program indicates"
PRINT SPC(10); "the best time to sample larvae within grassy areas."
   PRINT : PRINT
Question1:
   INPUT ; "           <R>eturn to main menu or <C>ontinue ? ", Ans$
   Ans$ = UCASE$(Ans$)
   IF Ans$ <> "R" AND Ans$ <> "C" THEN
      GOTO Question1
   ELSEIF Ans$ = "R" THEN
      CLS 2
      GOTO OpeningMenu
```

```
   ELSE
      CALL FileIn(Dayl%, DAYL%, Mday, Namel$, Name2$)
      CALL Borer(Mday, Sampl%, Samp2%, 0)
      CALL Graph(Menu, Jinsect%())
      PRINT ""
      INPUT ; "       Do you want a print out of data <Y or N>? ", Ans$
      IF UCASE$(Ans$) = "Y" THEN CALL Printl(Namel$, Name2$)
   END IF
   CLS 2
   GOTO OpeningMenu
'
CASE 3                'YIELD MODEL
'
   IF Nrun > 1 THEN
      ERASE Injplt, Cddsb, Fddsb, Phatch#, Pmove#, Fmove#, N, TotSb
      ERASE Cddc, Fddc, Cstage, Leaf%, PredYld, Healthy
      GOTO ChangeInput
   ELSE
      GOTO YieldModel
   END IF
'
CASE 4
'
   GOTO Finish
CASE ELSE
   GOTO OpeningMenu
END SELECT
ChangeInput:
   KEY OFF
   CLS 2: PRINT : PRINT
PRINT "     WEATHER DATA FILES:"
PRINT "         CURRENT: "; Namel$; "   FROM "; Dayl%; " TO "; DAYL%
PRINT "         AVERAGE: "; Name2$
PRINT "     GRASSY STRIP: "; Anl$
PRINT "         LENGTH (FEET): "; Tlength; "      WIDTH (FEET): "; Twidth
PRINT "         LARVAE/FT^2: "; Sbgl
PRINT "     FIELD DATA:"
PRINT "         IF NO GRASS STRIP:"
PRINT "         LENGTH (FEET): "; Flength; "     WIDTH (FEET): "; Fwidth
PRINT "         GRASS CLUMPS/YARD: "; GC; "  LARVAE/CLUMP: "; Sbfl
PRINT "     CROP DATA:"
PRINT "         PLANTING DATE: "; Jplant; "      PLANT POPULATION: "; Ppop
PRINT "         ROW WIDTH: "; Rwidth; "     MATURITY DEGREE DAYS: "; Mdd!
PRINT "     YIELD POTENTIAL:"; Potyld; " ADEQUATE SOIL MOISTURE: "; Soil$
PRINT "         PRICE/BU: "; Price
PRINT "     PESTICIDE APPLICATIONS:"
PRINT "         HERBICIDE: "; An2$; "        DATE: "; Herb%
PRINT "         INSECTICIDE: "; An3$; "       DATE: ";
PRINT Jinsect%(1, 1); Jinsect%(2, 1); Jinsect%(3, 1)
PRINT SPC(29); "AREA: "; Jinsect%(1, 2); Jinsect%(2, 2); Jinsect%(3, 2)
PRINT "         INSECTICIDE $/ACRE: "; Cost
```

```
PRINT " "
INPUT ; "     Do you wish to change parameter settings <Y or N>?", Cha$
Cha$ = UCASE$(Cha$)
IF Cha$ = "N" THEN
      CLS 2
      GOTO Calc
   ELSEIF Cha$ = "Y" THEN
       CLS 2: PRINT : PRINT
Menu2:
      PRINT SPC(15); "1.  Modify weather parameters"
      PRINT SPC(15); "2.  Modify field parameters and larval densities"
      PRINT SPC(15); "3.  Modify crop parameters"
      PRINT SPC(15); "4.  Modify herbicide application"
      PRINT SPC(15); "5.  Modify insecticide application"
      PRINT SPC(15); "6.  Reset all parameters"
      PRINT : PRINT :
      INPUT ; "          Enter selection <1-6>:", Change
      CLS 2
      SELECT CASE Change
         CASE 1
            KEY ON
            CALL FileIn(Dayl%, DAYL%, Mday, Name1$, Name2$)
            GOTO ChangeInput
         CASE 2
            KEY ON
            GOTO Grass
         CASE 3
            KEY ON
            GOTO Corn
         CASE 4
            KEY ON
            GOTO HerbApp
         CASE 5
            PRINT ""
PRINT SPC(10); "Before the number and timing of insecticide applications"
PRINT SPC(10); "can be modified, any changes to other parameters must be"
PRINT SPC(10); "made."
ChaInsect:
PRINT ""
INPUT ; "         Have all other changes been completed <Y or N>? ", Ans$
            Ans$ = UCASE$(Ans$)
            IF Ans$ = "Y" THEN
               CLS 2
               GOTO Calc
            ELSEIF Ans$ = "N" THEN
               GOTO ChangeInput
            ELSE
               PRINT SPC(15); "INVALID INPUT. PLEASE REENTER."
               GOTO ChaInsect
            END IF
         CASE 6
```

```
            Cha$ = "N"
            GOTO YieldModel
         CASE ELSE
            PRINT SPC(10); "INVALID INPUT.  PLEASE TRY AGAIN."
            GOTO Menu2
      END SELECT
   ELSE
      PRINT SPC(10); "INVALID INPUT. PLEASE TRY AGAIN."
      GOTO ChangeInput
   END IF
YieldModel:
   CLS 2: PRINT : PRINT : PRINT
PRINT SPC(10); "Selection 3 uses predicted movement of larvae"
PRINT SPC(10); "and corn development at the time of movement to estimate"
PRINT SPC(10); "the grain yield for a given area. If a grassy area"
PRINT SPC(10); "(terrace, waterway, or field edge) are present, yields"
PRINT SPC(10); "are predicted for the 8 rows adjacent to the grass."
PRINT
PRINT SPC(10); "To run this portion of the model the following"
PRINT SPC(10); "is needed:  current and/or 20-year average daily
temperature"
PRINT SPC(10); "and rainfall data for Jan. 1 to Aug. 1, julian day for"
PRINT SPC(10); "planting, degree days to reach maturity, plant"
PRINT SPC(10); "population, row width, field size, and density of grass"
PRINT SPC(10); "in the field.  You also have the option of entering the"
PRINT SPC(10); "density of stalk borer larvae within the field or
PRINT SPC(10); "selecting from a menu."
PRINT : PRINT
Question2:
   INPUT ; "          <R>eturn to main menu or <C>ontinue ? ", Ans$
   Ans$ = UCASE$(Ans$)
   IF Ans$ <> "R" AND Ans$ <> "C" THEN
      GOTO Question2
   ELSEIF Ans$ = "R" THEN
      CLS 2
      GOTO OpeningMenu
   ELSE

'
'Accessing current and 20-year average weather data files and
'initializing growth stage and injury arrays.
'
   CALL FileIn(Dayl%, DAYL%, Mday, Namel$, Name2$)
'
'This section of the program inputs information from the keyboard
'concerning planting, pesticide applications, initial densities of larvae
'in the grass, and field dimensions.
'
Grass:
   CLS 2
PRINT : PRINT
```

```
PRINT SPC(10); "Stalk borer eggs are laid during the fall, mostly on "
PRINT SPC(10); "perennial grass found within the field or in grassy "
PRINT SPC(10); "area, such as terraces, waterways, and field edges. "
PRINT SPC(10); "movement of stalk borers from grassy areas to corn tends"
PRINT SPC(10); "to be restricted to the 8 rows adjacent to the grassy"
PRINT SPC(10); " area."
   PRINT
Grassdat:
INPUT ; "        Is a grassy strip present in the field <Y or N>? ", An1$
   An1$ = UCASE$(An1$)
   IF An1$ = "N" THEN
      Twidth = 0
      Tlength = 0
      Sbgl = 0
      PRINT
PRINT SPC(10); "Because no grassy area is present, the dimensions of the"
PRINT SPC(10); "field need to be entered."
PRINT
INPUT ; "          Enter the length of the field (in feet): ", Flength
PRINT
INPUT ; "          Enter the width of the field (in feet): ", Fwidth
ELSEIF An1$ = "Y" THEN
PRINT : PRINT
PRINT SPC(10); "The model assumes that the size of the field is 8 rows"
PRINT SPC(10); "wide and as long as the grassy area."
PRINT : PRINT
INPUT ; "      Enter the length of the grassy area (in feet): ", Tlength
PRINT : PRINT
INPUT ; "      Enter the width of the grassy area (in feet): ", Twidth
CLS 2
PRINT : PRINT
PRINT SPC(10); "An initial estimate of stalk borer density in the grassy"
PRINT SPC(10); "area is needed to initialize the program.  You have the"
PRINT SPC(10); "option of estimating stalk borer numbers after egg hatch"
PRINT SPC(10); "or entering the density of 2nd, 3rd, and 4th instars as"
PRINT SPC(10); "determined from samples taken from the grass."
PRINT : PRINT
      PRINT SPC(20); "OPTION      Density/ft^2"
      PRINT : PRINT
      PRINT SPC(20); "<Z>ero          0"
      PRINT SPC(20); "<L>ow           0.5"
      PRINT SPC(20); "<M>edium        1.0"
      PRINT SPC(20); "<H>igh          2.0"
      PRINT SPC(20); "<V>ery high     5.0"
      PRINT SPC(20); "<A>ctual        User Input"
      PRINT : PRINT
Density:
      INPUT ; "          Enter selection <Z,L,M,H,V,A>: ", D$
      D$ = UCASE$(D$)
      SELECT CASE D$
         CASE "A"
```

```
            CLS 2
            PRINT : PRINT
PRINT SPC(10); "You have elected to input actual density of larvae"
PRINT SPC(10); "in the grassy areas."
PRINT : PRINT
INPUT ; "           Enter the larval density (larvae/ft^2): ", Sbgl
            Gtime$ = "CDD500"
         CASE "Z"
            Sbgl = 0
            Gtime$ = "HATCH"
         CASE "L"
            Sbgl = .5
            Gtime$ = "HATCH"
         CASE "M"
            Sbgl = 1!
            Gtime$ = "HATCH"
         CASE "H"
            Sbgl = 2!
            Gtime$ = "HATCH"
         CASE "V"
            Sbgl = 5!
            Gtime$ = "HATCH"
         CASE ELSE
            PRINT : PRINT SPC(10); "INVALID ENTRY. PLEASE TRY AGAIN."
            PRINT : PRINT
            GOTO Density
      END SELECT
   ELSE
      PRINT "INVALID ENTRY. PLEASE TRY AGAIN"
      PRINT : PRINT
      GOTO Grassdat
   END IF
   CLS 2: PRINT : PRINT
PRINT SPC(10); "Eggs may be laid within the field itself, especially if"
PRINT SPC(10); "perennial grasses, such as orchardgrass, quackgrass, or"
PRINT SPC(10); "wirestem muhly, are present."
Eggs:
   PRINT : PRINT
PRINT SPC(10); "Enter the average number of grass clumps per yard of row"
INPUT ; "           <a real number between 0 and 3>: ", GC
   IF (GC >= 0 AND GC <= 3) THEN
Clump:
      PRINT : PRINT : PRINT
      PRINT SPC(20); "OPTION       LARVAE/CLUMP"
      PRINT : PRINT
      PRINT SPC(20); "<Z>ero          0"
      PRINT SPC(20); "<L>ow           0.5"
      PRINT SPC(20); "<M>edium        1.0"
      PRINT SPC(20); "<H>igh          2.0"
      PRINT SPC(20); "<V>ery high     5.0"
      PRINT SPC(20); "<A>ctual        User Input"
```

```
      PRINT : PRINT
      INPUT ; "          Enter selection <Z,L,M,H,V,A>: ", Dg$
      Dg$ = UCASE$(Dg$)
      SELECT CASE Dg$
         CASE "A"
            CLS 2
            PRINT : PRINT
PRINT SPC(10); "Please enter the average number of larvae in each"
            INPUT ; "          grass clump: ", Sbfl
            Ftime$ = "CDD500"
         CASE "Z"
            Sbfl = 0
            Ftime$ = "HATCH"
         CASE "L"
            Sbfl = .5
            Ftime$ = "HATCH"
         CASE "M"
            Sbfl = 1!
            Ftime$ = "HATCH"
         CASE "H"
            Sbfl = 2!
            Ftime$ = "HATCH"
         CASE "V"
            Sbfl = 5!
            Ftime$ = "HATCH"
         CASE ELSE
            PRINT : PRINT SPC(10); "INVALID ENTRY. PLEASE TRY AGAIN."
            PRINT : PRINT
            GOTO Clump
      END SELECT
   ELSE
      PRINT : PRINT
      PRINT SPC(10); "INVALID ENTRY. PLEASE TRY AGAIN."
      GOTO Eggs
   END IF
   CLS 2
   IF Cha$ = "Y" THEN GOTO ChangeInput
Corn:
   KEY ON
   DO WHILE Jplant = 0
      PRINT : PRINT
INPUT ; "      Enter the Julian date that corn will be planted: ", Jplant
   LOOP
   PRINT : PRINT
PRINT SPC(10); "This program models corn development using fahrenheit"
PRINT SPC(10); "degree days.  The model adjusts development on the basis"
PRINT SPC(10); "of growing degree days required for the hybrid to reach
PRINT SPC(10); "maturity."
PRINT : PRINT
INPUT ; "       Enter the growing degree days to reach maturity: ", Mdd!
PRINT : PRINT
```

```
INPUT ; "          What is the yield potential (in bu./acre): ", Potyld
Msoil:
PRINT : PRINT
INPUT ; "          Was corn planted into moist soil <Y or N>? ", Soil$
   Soil$ = UCASE$(Soil$)
   IF Soil$ <> "Y" AND Soil$ <> "N" THEN
      PRINT SPC(10); "Re-enter soil moisture condition."
      GOTO Msoil
   END IF
   PRINT : PRINT
   INPUT ; "       Enter the initial plant population per acre: ", Ppop
   PRINT : PRINT
   INPUT ; "          Enter the row spacing in inches: ", Rwidth
   PRINT : PRINT
   INPUT ; "          Enter the price of corn ($/bu): ", Price
   CLS 2
   IF Cha$ = "Y" THEN GOTO ChangeInput
   PRINT : PRINT
   IF Dg$ <> "Z" THEN      'Determine if a herbicide is applied
HerbApp:
PRINT " "
PRINT SPC(10); "Application of a herbicide may force larvae to migrate"
PRINT SPC(10); "from grasses within the field sooner than expected."
PRINT SPC(10); "Will a herbicide be applied to kill perennial grasses"
      INPUT ; "          in the field <Y or N>? ", An2$
      An2$ = UCASE$(An2$)
      IF An2$ = "Y" THEN
         PRINT : PRINT
PRINT SPC(10); "Herbicides to kill perennial grasses must be applied"
PRINT SPC(10); "before corn emerges or the corn will be killed.  In this"
PRINT SPC(10); "simulation, corn is planted on julian date"; Jplant; "."
         DO WHILE Herb% = 0
            PRINT : PRINT
INPUT ; "       Enter the julian date for herbicide application: ", Herb%
         LOOP
      ELSEIF An2$ = "N" THEN
         Herb% = 0
      ELSE
         PRINT : PRINT
         PRINT SPC(10); "INVALID ENTRY. PLEASE TRY AGAIN"
         GOTO HerbApp
      END IF
      CLS 2
   ELSE
      Herb% = 0
   END IF
   CLS 2
   IF Cha$ = "Y" THEN GOTO ChangeInput
Calc:
   KEY OFF
   PRINT : PRINT
```

```
   PRINT SPC(25); "CALCULATIONS ARE IN PROGRESS"
'
'The following program section determines corn growth stage, predicts
'stalk borer hatch and movement, determines the distribution of injury in
'the field, and predicts final grain yield.
'
   CALL Cgrow(Mday, Jplant, Mdd!, Soil$, Stress)
   CALL Borer(Mday, Sampl%, Samp2%, Herb%)
   CALL Graph(Menu, Jinsect%())
   FOR NUM = 1 TO 8
      PRINT ""
   NEXT NUM
   PRINT SPC(25); "CALCULATIONS ARE IN PROGRESS"
'
'Determining initial number of stalk borers in the field
'
   IF Twidth > 10 THEN Twidth = 10
   Nsbgl! = Tlength * Twidth * Sbgl
   IF Anl$ = "Y" THEN           'Terrace situation
      GrassN = Tlength * 8 * GC / 3
      Nrow = 8
      Ppopr = Ppop * Tlength / (43560 * 12 / Rwidth)
      Acres = Tlength * 8 * (Rwidth / 12) / 43560
   ELSE                         'No terraces in field
      GrassN = Flength * Fwidth / (Rwidth / 12) * GC / 3
      Nrow = 1
      Ppopr = Ppop * Flength * Fwidth / 43560
      Acres = Flength * Fwidth / 43560
   END IF
   Nsbfl! = GrassN * Sbfl
'
'Determining the number of larvae that were able to survive after
'hatching.  Daily mortality is affected by rainfall.
'
   M = Mday - 1
   Fl = Nsbfl!
   Gl = Nsbgl!
   FOR I = 1 TO M
      IF Phatch#(I) > .001 AND Phatch#(I) < .999 THEN
         IF weather(I, 4) < .5 THEN
            Mort = .2
         ELSEIF weather(I, 4) >= 1.5 THEN
            Mort = .8
         ELSE
            Mort = .5
         END IF
         dead# = Mort * (Phatch#(I) - Phatch#(I - 1))
         IF Ftime$ = "HATCH" THEN
            Nsbfl! = Nsbfl! - dead# * Fl
         END IF
         IF Gtime$ = "HATCH" THEN
```

```
            Nsbgl! = Nsbgl! - dead# * Gl
         END IF
      END IF
   NEXT I
'
'Determining the number of stalk borers that successfully move from grass
'to corn on each day.
'
   FOR JIN = 1 TO 2
      FOR J = 1 TO Nrow
         Healthy(JIN, J) = Ppopr
   NEXT J, JIN
   FOR I = 1 TO M
      IF Pmove#(I) > .001 AND Pmove#(I) < .999 THEN
         Gdif# = Pmove#(I) - Pmove#(I - 1)
      ELSE
         Gdif# = 0
      END IF
   '
   'Determining movement of larvae from grasses within the field
   '
      IF Fmove#(I) > .001 AND Fmove#(I) < .999 THEN
         Fdif# = Fmove#(I) - Fmove#(I - 1)
      ELSE
         Fdif# = 0
      END IF
      IF Leaf%(I) > 7 THEN
         L = 7
      ELSE
         L = Leaf%(I)
      END IF
'
'Determining the distribution of larvae in the field.
'
      FOR JIN = 1 TO 2
         FOR J = 1 TO Nrow
            IF JIN = 1 THEN
               Survive = .5
            ELSE
               Survive = Surv(I, J, Jinsect%())
            END IF
            RowNg# = Gdif# * Nsbgl * (-.0308 + .4402 / J) * Survive
            RowNf# = Fdif# * Nsbfl / Nrow * Survive
            N(JIN, I, J) = RowNg# + RowNf#
'
'Determine the number of larvae that survived in the field before plants
'emerged.
'
            Delay = 0!
            IF I > 1 THEN
               IF Leaf%(I - 1) = 0 AND Leaf%(I) = 1 THEN
```

```
                  FOR D = 1 TO 5
                     Delay = Delay + N(JIN, I - D, J) * (6 - D) / 5
                  NEXT D
               END IF
            END IF
'
'Determine the number of plants attacked.  Assumes initially one larva/
'plant until all plants are attacked.
'
            IF N(JIN, I, J) + Delay > Healthy(JIN, J) THEN
               Attack = Healthy(JIN, J)
            ELSE
               Attack = N(JIN, I, J) + Delay
            END IF
'
'If corn is up, plants will be attacked.  Otherwise larvae are
'assumed to die.
'
            IF L > 0 THEN
               Healthy(JIN, J) = Healthy(JIN, J) - Attack
               FOR R% = 2 TO 6
Injplt(JIN,J,L,R%) = Injplt(JIN,J,L,R%) + Injury(L, R%) * Attack / Ppopr
               NEXT R%
            END IF
         NEXT J
         FOR J = 1 TO Nrow
            TotSb(JIN, I) = TotSb(JIN, I) + N(JIN, I, J)
         NEXT J
      NEXT JIN
   NEXT I
'
'Determining the final yield for each row (noncrop area present) or field
'
   FOR JIN = 1 TO 2
      FOR J = 1 TO Nrow
         PredYld(JIN, J) = Yield#(JIN, J, Stress, Potyld)
   NEXT J, JIN
   CLS 2
   PRINT " ": PRINT " "
   PRINT SPC(22); "CALCULATIONS HAVE BEEN COMPLETED."
   PRINT : PRINT
   INPUT ; "     Print out projected hatch and movement <Y or N>? ", An4$
   An4$ = UCASE$(An4$)
   PRINT : PRINT
INPUT ; "  Print out corn development and insect counts <Y or N>? ", An5$
   An5$ = UCASE$(An5$)
   PRINT : PRINT
   INPUT ; "     Print out yield predictions <Y or N>? ", An6$
   An6$ = UCASE$(An6$)
   PRINT : PRINT
   IF An4$ = "Y" OR An5$ = "Y" OR An6$ = "Y" THEN
```

```
LPRINT SPC(5);
"________________________________________________________________________"
LPRINT : LPRINT
LPRINT "                 SIMULATION OF STALK BORER LARVAE INFESTING CORN"
LPRINT "
_______________________________________________________________________"
LPRINT : LPRINT
LPRINT "                                 INPUT PARAMETERS"
LPRINT : LPRINT
LPRINT "         WEATHER DATA FILES:"
LPRINT "             CURRENT: "; Name1$; "  FROM "; Day1%; " TO "; DAYL%
LPRINT "             AVERAGE: "; Name2$
LPRINT : LPRINT
LPRINT "         GRASSY STRIP: "; An1$
LPRINT "            LENGTH (FEET): "; Tlength; " WIDTH (FEET): "; Twidth
LPRINT "            LARVAE/FT^2: "; Sbg1
LPRINT : LPRINT
LPRINT "         FIELD DATA:"
LPRINT "             IF NO GRASS STRIP:"
LPRINT "             LENGTH (FEET): "; Flength; "WIDTH (FEET): "; Fwidth
LPRINT "             GRASS CLUMPS/YARD OF ROW: "; GC
LPRINT "             LARVAE/CLUMP: "; Sbf1
LPRINT : LPRINT
LPRINT "         CROP DATA:"
LPRINT "             PLANTING DATE:"; Jplant; "PLANT POPULATION: "; Ppop
LPRINT "             ROW WIDTH: ";Rwidth;" MATURITY DEGREE DAYS: "; Mdd!
LPRINT "  YIELD POTENTIAL: "; Potyld; "ADEQUATE SOIL MOISTURE: "; Soil$
LPRINT "             PRICE/BUSHEL: $"; Price
LPRINT : LPRINT
LPRINT "         PESTICIDE APPLICATIONS:"
LPRINT "             HERBICIDE: "; An2$; "        DATE: "; Herb%
LPRINT "             INSECTICIDE: "; An3$; "      DATE: ";
LPRINT Jinsect%(1, 1); Jinsect%(2, 1); Jinsect%(3, 1)
LPRINT "                                  Rows:";
LPRINT Jinsect%(1, 2); Jinsect%(2, 2); Jinsect%(3, 2)
LPRINT "             INSECTICIDE COST/ACRE: $"; Cost
LPRINT "
_______________________________________________________________________"
      LPRINT STRING$(1, 12)
      IF An4$ = "Y" THEN CALL Print1(Name1$, Name2$)
   END IF
   CALL Print2(Nrow, Ppopr)
   Nrun = Nrun + 1
   GOTO OpeningMenu
END IF
Finish:
   CLS 2
   SYSTEM
'
'Look up table of Julian dates for leap years and nonleap years.
'
```

```
Julian:
   CLS 2
   IF Remain <> 0 THEN
      PRINT "
_____________________________________________________________________"
PRINT "                                    Julian Date"
PRINT "  Calendar "
PRINT "     day     Jan     Feb     Mar     Apr     May     Jun     Jul     Aug"
PRINT "
_____________________________________________________________________"
PRINT ""
PRINT "      1       1      32      60      91     121     152     182     213"
PRINT "     10      10      41      69     100     130     161     191"
PRINT "     20      20      51      79     110     140     171     201"
PRINT "     30      30      --      89     120     150     181     211"
PRINT "
_____________________________________________________________________"
ELSE
PRINT "
_____________________________________________________________________"
PRINT "                                    Julian Date"
PRINT "  Calendar"
PRINT "     day     Jan     Feb     Mar     Apr     May     Jun     Jul     Aug"
PRINT "
_____________________________________________________________________"
PRINT ""
PRINT "      1       1      32      61      92     122     153     183     214"
PRINT "     10      10      41      70     101     131     162     192"
PRINT "     20      20      51      80     111     141     172     202"
PRINT "     30      30      --      90     121     151     182     212"
PRINT "
_____________________________________________________________________"
   END IF
   PRINT ""
   PRINT "  Press any key to continue."
   DO
   LOOP WHILE INKEY$ = ""
   CLS 0
   RETURN

'************************************************************************
SUB Borer (Mday, Samp1%, Samp2%, Herb%)
'************************************************************************
'
'This subroutine predicts egg hatch and larval movement into corn.
'Suggested dates for sampling grass for larvae are given.
'
SHARED weather(), Cddsb(), Fddsb(), Phatch#(), Pmove#(), Fmove#()
DIM Tmin(1 TO 2)
S1% = 0
S2% = 0
```

```
N = Mday - 1
'
'Accumulating April rainfall
'
IF Mday = 213 THEN Leap = 0:                    ELSE Leap = 1
Arain = 0
FOR X = 91 + Leap TO 120 + Leap
   Arain = Arain + weather(X, 4)
NEXT X
FOR I = 1 TO N
   Tmax = weather(I, 2)
   Tmin(1) = weather(I, 3)
   Tmin(2) = weather(I + 1, 3)
   Dday = Degday#(1, Tmin(), Tmax)
   IF I = 1 THEN
      Cddsb(1) = Dday
   ELSE
      Cddsb(I) = Cddsb(I - 1) + Dday
   END IF
   Fddsb(I) = Cddsb(I) * 9 / 5
'
'Calculation of percent hatching.  If April rainfall is below 10 cm, the
'equation from 1985 is used.  Equation, based on 1984 data, is used if
'rainfall exceeds 10 cm.
'
   IF Arain < 10 THEN
      Y1# = 9.95 - .0292 * Cddsb(I)
   ELSE
      Y1# = 16.8 - .0417 * Cddsb(I)
   END IF
   Phatch#(I) = 1 / (1 + EXP(Y1#))
'
'Determine the best time to sample grass for larvae
'
   SELECT CASE S1%
      CASE 0
         IF Cddsb(I) > 499 THEN
            Samp1% = I
            S1% = 1
         END IF
      CASE 1
         IF S2% = 0 THEN
            IF Cddsb(I) > 600 THEN
               Samp2% = I
               S2% = 1
            END IF
         END IF
      END SELECT
'
'Calculation of natural movement from grass to corn (no herbicides
'have been applied to induce early movement) as a proportion of the
```

```
'number of larvae in grass before movement begins.
'
   Y2# = 26.091-.0529*Cddsb(I)+.000034*Cddsb(I)^2-8.3E-09 * Cddsb(I)^3
   Pmove#(I) = 1 / (1 + EXP(Y2#))
'
'Calculation of movement within the field.  Movement is modeled by using
'a chi-square cumulative distribution function with 6 df.
'
   IF Herb% = 0 OR I < Herb% + 2 THEN
      Fmove#(I) = Pmove#(I)
   ELSE
      T = (I - Herb% - 1) / 2
      FM# = 1 - EXP(-T) * (1 + T + (T ^ 2) / 2)
      IF Cddsb(Herb% + 2) < 510 THEN
         PH# = Phatch#(Herb% + 2)
         Fmove#(I) = PH# * FM# + Phatch#(I) - PH#
      ELSE
         Fmove#(I) = Pmove#(Herb% + 2) + (1 - Pmove#(Herb% + 2)) * FM#
      END IF
   END IF
NEXT I
END SUB

'************************************************************************
SUB Cgrow (Mday, Jplant, Mdd!, Soil$, Stress)
'************************************************************************
'
'This subroutine calculates corn development by using the development
'equation reported by Neild & Seeley (1977).  The subroutine calls the
'function Degday and accumulates degree days.
'
SHARED weather(), Cddc(), Fddc(), Cstage() AS SINGLE
SHARED Leaf%(), GROW!()
DIM Tmin(1 TO 2)
Slope# = (1 / 125.5) - Mdd! * 1.533E-06
N = Jplant - 1
Switch% = 0
M = Mday - 1
IF Mday = 214 THEN
   N1 = 92
   N2 = 182
ELSE
   N1 = 91
   N2 = 181
END IF
Rain = 0
FOR I = 1 TO M
   IF I < Jplant THEN
      Cddc(I) = 0!
      Fddc(I) = 0!
      Cstage(I) = -.31
```

```
   ELSE
      IF ((UCASE$(Soil$) <> "N") OR (weather(I, 4) > .5)) THEN Switch%=1
      IF Switch% = 1 THEN
         Tmin(1) = weather(I, 3)
         Tmin(2) = weather(I + 1, 3)
         Tmax = weather(I, 2)
         Dday = Degday#(2, Tmin(), Tmax)
         Cddc(I) = Cddc(I - 1) + Dday
         Fddc(I) = 9 / 5 * Cddc(I)
         Cstage(I) = -.31 + Slope# * Fddc(I)
         Leaf%(I) = Search%(Cstage(I))
      END IF
   END IF
   IF I >= N1 AND I <= N2 THEN Rain = Rain + weather(I, 4)
NEXT I
IF Rain < 15 THEN
   Stress = 0
ELSE
   Stress = 1
END IF
END SUB

'************************************************************************
FUNCTION Convert (Dat, J, Tscale$, Pscale$)
'************************************************************************
'
'This function converts temperature and rainfall to celcius and cm,
'respectively.
'
IF ((J = 4) AND (Pscale$ = "IN")) THEN
   Convert = Dat * 2.54
ELSEIF (J = 2 OR J = 3) AND Tscale$ = "F" THEN
   Convert = (Dat - 32) * 5 / 9
ELSE
   Convert = Dat
END IF
END FUNCTION

'************************************************************************
FUNCTION Degday# (SBorC, Tmin(), Tmax)
'************************************************************************
'
'This function determines the centigrade degree days for a single day
'using the sine-wave method.  This section of programming is modified
'from the computer model DEGDAY (Higley et al. 1986)
'
DIM Hsine(2)
IF SBorC = 1 THEN
   Dmin = 5.1
   Dmax = 1000
ELSE
```

```
   Dmin = 10
   Dmax = 30
END IF
FOR I = 1 TO 2
   A = (Tmax - Tmin(I)) / 2
   Mt = (Tmax + Tmin(I)) / 2
   IF Tmin(I) >= Dmax AND Tmax > Dmax THEN
      M1 = 1
   ELSEIF Tmin(I) < Dmin AND Tmax <= Dmin THEN
      M1 = 2
   ELSEIF Tmin(I) >= Dmin AND Tmax <= Dmax THEN
      M1 = 3
   ELSEIF Tmin(I) < Dmin AND Tmax <= Dmax THEN
      M1 = 4
   ELSEIF Tmin(I) >= Dmin AND Tmax > Dmax THEN
      M1 = 5
   ELSE
      M1 = 6
   END IF
   SELECT CASE M1
      CASE 1
         Hsine(I) = (Dmax - Dmin) / 2
      CASE 2
         Hsine(I) = 0
      CASE 3
         Hsine(I) = (Mt - Dmin) / 2
      CASE 4
         X1 = (Dmin - Mt) / A
         T1 = ATN(X1 / SQR(1 - X1 ^ 2))
         T2 = 1.5708
      CASE 5
         X2 = (Dmax - Mt) / A
         T1 = -1.5708
         T2 = ATN(X2 / SQR(1 - X2 ^ 2))
      CASE 6
         X1 = (Dmin - Mt) / A
         X2 = (Dmax - Mt) / A
         T1 = ATN(X1 / SQR(1 - X1 ^ 2))
         T2 = ATN(X2 / SQR(1 - X2 ^ 2))
   END SELECT
   IF M1 > 3 THEN
      P1 = (Mt - Dmin) * (T2 - T1)
      P2 = A * (COS(T1) - COS(T2)) + (Dmax - Dmin) * (1.5708 - T2)
      Hsine(I) = .159155 * (P1 + P2)
   END IF
NEXT I
Degday# = Hsine(1) + Hsine(2)
END FUNCTION

'
'************************************************************************
```

```
SUB FileIn (Dayl%, DAYL%, Mday, Namel$, Name2$)
'***********************************************************************
SHARED weather(), GROW!()
SHARED Injury(), Remain
DIM Avgw(1 TO 214, 1 TO 4), Cweath(1 TO 214, 1 TO 4) AS SINGLE
'
'This subroutine uploads 20-year average weather data and current weather
'data.  Names of these files are input by user.  Array GROW holds
'information on corn growth input from GROWTH.DAT.  Array Injury contains
'information on the severity of injury for leaf stages 1 through 7.
'
CLS 2: PRINT : PRINT :
INPUT ; "         Enter the year for the simulation: ", Year
Remain = Year MOD 4
PRINT : PRINT
PRINT SPC(10); "Enter the name of the file containing weather data for"
INPUT ; "         the current year: ", Namel$
PRINT : PRINT
INPUT ; "  Enter the scale for temperature data <F or C>: ", Tscalel$
Tscalel$ = UCASE$(Tscalel$)
PRINT : PRINT
INPUT ; "  Enter the scale for precipitation data <IN or CM>: ", Pscalel$
Pscalel$ = UCASE$(Pscalel$)
KEY ON
PRINT : PRINT
PRINT SPC(10); "This simulation uses weather data from January 1 through"
PRINT SPC(10); "August 1, which corresponds to Julian dates 1 and 213"
PRINT SPC(10); "(214 in a leap year).  If complete weather data is not"
PRINT SPC(10); "available, 20-year-average weather data is used to "
PRINT SPC(10); "project stalk borer and corn phenology."
DO WHILE Dayl% = 0
   PRINT : PRINT
   PRINT SPC(10); "Enter the julian date of the first day current "
   INPUT ; "         weather data is available: ", Dayl%
LOOP
DO WHILE DAYL% = 0
   PRINT : PRINT
   INPUT ; "  Enter last day current weather data is available: ", DAYL%
LOOP
IF Remain = 0 THEN
   Mday = 214
ELSE
   Mday = 213
END IF
CLS 2
IF NOT (Dayl% = 1 AND DAYL% >= Mday) THEN
Average:
PRINT : PRINT
PRINT SPC(10); "Current year weather data is not complete.  More data"
PRINT SPC(10); "is needed from a file containing 20-year-average weather"
INPUT ; "      data.  Enter name of file containing these data: ", Name2$
```

```
 PRINT : PRINT
 INPUT ; "      Enter the scale for temperature data <C or F>: ", Tscale2$
    Tscale2$ = UCASE$(Tscale2$)
    PRINT : PRINT
 INPUT ; "  Enter the scale for precipitation data <IN or CM>: ", Pscale2$
    Pscale2$ = UCASE$(Pscale2$)
    PRINT : PRINT
    PRINT SPC(20); "INPUTTING AVERAGE WEATHER DATA FROM FILE."
    PRINT
    OPEN Name2$ FOR INPUT AS #2
    FOR I = 1 TO Mday
       FOR J = 1 TO 4
          INPUT #2, Avgw(I, J)
          weather(I, J) = Convert(Avgw(I, J), J, Tscale2$, Pscale2$)
       NEXT J
    NEXT I
    CLOSE #2
END IF
PRINT : PRINT
PRINT SPC(20); "INPUTTING CURRENT WEATHER DATA FROM FILES."
IF DAYL% > Mday THEN DAYL% = Mday
OPEN Name1$ FOR INPUT AS #1
K = DAYL% - Dayl% + 1
FOR I = 1 TO K
   FOR J = 1 TO 4
      Date% = I + Dayl% - 1
      INPUT #1, Cweath(I, J)
      IF Cweath(I, J) = 999 THEN
         IF Name2$ = "" THEN
            CLOSE #1
            GOTO Average
         END IF
      ELSE
         weather(Date%, J) = Convert(Cweath(I, J), J, Tscale1$, Pscale1$)
      END IF
   NEXT J
NEXT I
CLOSE #1
KEY OFF
OPEN "GROWTH.DAT" FOR INPUT AS #3
FOR I = 1 TO 26
   FOR J = 1 TO 2
      INPUT #3, GROW!(I, J)
NEXT J, I
CLOSE #3
OPEN "INJURY.DAT" FOR INPUT AS #4
FOR I = 1 TO 7
   FOR J = 2 TO 6
      INPUT #4, Injury(I, J)
   NEXT J
NEXT I
```

```
CLOSE #4
END SUB

'************************************************************************
SUB Graph (Menu, Jinsect%())
'************************************************************************
'
'This subroutine plots stalk borer hatch and movement from grass to corn.
'If accessed from the Yield Model, input on insecticide usage is
'requested.
'
SHARED Phatch#(), Pmove#(), Fmove#(), Leaf%(), An3$, Herb%, Jplant
SHARED AppN, An1$, Cost
DIM ARRAY1(250), ARRAY2(250), ARRAY3(250)
DIM Stage(7) AS INTEGER
SCREEN 8
Again:
CLS 0
VIEW (40, 30)-(633, 125), 1, 16
WINDOW (100, 0)-(200, 100)
COLOR 15
LOCATE 10, 40: PRINT "Movement"
GET (145.8, 49)-(156.5, 56), ARRAY1
LOCATE 10, 60: PRINT "Hatch"
GET (172.8, 49)-(179.5, 56), ARRAY2
LOCATE 10, 20: PRINT "Field"
GET (119!, 49)-(125.3, 56), ARRAY3
CLS 0
VIEW (40, 30)-(633, 125), 1, 16
WINDOW (100, 0)-(200, 100)
I = 100
DO WHILE Phatch#(I) < .5
   I = I + 1
LOOP
PUT ((I + 2), 50), ARRAY2, XOR
I = 100
DO WHILE Pmove#(I) < .5
   I = I + 1
LOOP
PUT ((I + 2), 50), ARRAY1, XOR
IF Menu = 3 THEN
   IF Herb% <> 0 THEN
      I = 100
      DO WHILE Fmove#(I) < .3
         I = I + 1
      LOOP
      PUT ((I + 2), 30), ARRAY3, XOR
   END IF
END IF
'
'LABEL Y AXIS
```

```
'
N = 100
FOR I = 4 TO 17 STEP 3
   LOCATE I, 1: PRINT N
   N = N - 25
NEXT I
'
'PUT TICKS ON Y-AXIS
'
FOR I = 0 TO 100 STEP 25
   LINE (100, I)-(101, I), 14
NEXT I
'
'PUT TICKS ON X-AXIS'
'
FOR I = 100 TO 200 STEP 10
  LINE (I, 0)-((I + .25), 1), 14, BF
NEXT I
'
'LABEL X-AXIS'
'
N = 100
FOR I = 1 TO 74 STEP 14.72
   LOCATE 18, I + 3: PRINT N
   N = N + 20
NEXT I
LOCATE 18, 78: PRINT "200"
COLOR 14
LOCATE 1, 30: PRINT "STALK BORER HATCH & MOVEMENT"
LOCATE 3, 6: PRINT "Percent"
LOCATE 19, 37: PRINT "Julian Date"
'
'Plotting hatch, movement from grass in the field, and movement from
'grass in noncrop areas.
'
FOR I = 100 TO 200
   I2 = I + 1
   IF I = 100 THEN LINE (I, (Phatch#(I)*100))-(I2, (Phatch#(I2)*100)), 15
   IF I > 100 THEN LINE -(I2, (Phatch#(I2) * 100)), 15
NEXT I
FOR I = 100 TO 200
   I2 = I + 1
   IF I = 100 THEN LINE (I, (Pmove#(I)*100))-(I2, (Pmove#(I2) * 100)), 15
   IF I > 100 THEN LINE -(I2, (Pmove#(I2) * 100)), 15
NEXT I
IF Menu = 3 THEN
   IF Herb% <> 0 THEN
      FOR I = 100 TO 200
         I2 = I + 1
         IF I = 100 THEN LINE (I,(Fmove#(I)*100))-(I2,(Fmove#(I2)*100)),5
         IF I > 100 THEN LINE -(I2, (Fmove#(I2) * 100)), 5
```

```
      NEXT I
   END IF
'
'Determining the julian date when corn reaches the 1-leaf, 4-leaf, and 7-
'leaf stage of development.
'
   FOR L = 1 TO 7 STEP 3
      J = Jplant
      DO WHILE Leaf%(J) < L
         J = J + 1
         IF J > 200 THEN EXIT DO
      LOOP
      Stage(L) = J
   NEXT L
   COLOR 15
   LOCATE 20, 30: PRINT "1-LEAF   4-LEAF   7-LEAF"
   LOCATE 21, 15: PRINT "JULIAN DATE      ";
   PRINT USING "###      "; Stage(1); Stage(4); Stage(7)
   COLOR 14
   VIEW PRINT 22 TO 25
Insect:
PRINT " An insecticide may be applied to reduce losses from stalk borer."
PRINT " Applications are made soon after planting (such as in a no-till"
PRINT " situation) or when larvae are moving from grassy areas to corn."
INPUT ; "  Will an insecticide be applied <Y or N>? ", An3$
   An3$ = UCASE$(An3$)
   IF An3$ <> "Y" AND An3$ <> "N" THEN CLS 2: GOTO Insect
   ERASE Jinsect%
   IF An3$ = "Y" THEN
Apply:
      CLS 2
      PRINT ""
      INPUT ; "  How many applications <1, 2, or 3>? ", AppN
      IF AppN <> 1 AND AppN <> 2 AND AppN <> 3 THEN GOTO Apply
      PRINT " "
      INPUT ; "  Cost of each application ($/acre): ", Cost
      FOR I = 1 TO AppN
         CLS 2
         PRINT ""
         PRINT "  Enter the julian date for application ";
         PRINT USING "#"; I;
         INPUT ; ": ", Jinsect%(I, 1)
         IF An1$ = "N" THEN
            Jinsect%(I, 2) = 1
         ELSE
NSpray:
            PRINT " "
INPUT ; "  Enter the number of rows sprayed <4 or 8> :"; Jinsect%(I, 2)
            IF Jinsect%(I, 2) <> 4 AND Jinsect%(I, 2) <> 8 THEN
               PRINT "  Please reenter."
               GOTO NSpray
```

```
            END IF
         END IF
      NEXT I
   END IF
   CLS 2
ELSE
   PRINT "Press any key to continue."
   DO
   LOOP WHILE INKEY$ = ""
END IF
CLS 0
VIEW PRINT 1 TO 25
COLOR 7, 1
PRINT : PRINT : PRINT
END SUB
'************************************************************************
SUB Instruct
'************************************************************************
InstructMenu:
CLS 2
PRINT : PRINT : PRINT
PRINT SPC(35); "MENU"
PRINT ""
PRINT SPC(25); "1.  Overview of SBMGMT"
PRINT SPC(25); "2.  Weather files"
PRINT SPC(25); "3.  Missing data in weather files"
PRINT SPC(25); "4.  Model Input and Output"
PRINT SPC(25); "5.  Return to main menu"
PRINT ""
   INPUT ; "               Enter menu selection <1-5>: ", Menu
SELECT CASE Menu
   CASE 1
      CLS 2
      PRINT : PRINT
      PRINT SPC(20); "Overview of SBMGMT"
      PRINT " "
PRINT "       SBMGMT is a management model which predicts stalk borer
(Papaipema"
PRINT " nebris) phenology, movement, and yield losses in corn.  The
model was"
PRINT " formulated with three primary objectives: (1) to accurately
forecast egg"
PRINT " hatch, larval movement, and stage of corn development, (2) to
predict "
PRINT " yield losses to corn in terrace and no-tillage systems, and (3)
to"
PRINT " evaluate the effectiveness of cultural practices (herbicide
application"
PRINT " and planting date) and insecticide programs in reducing yield
losses."
PRINT "       SBMGMT is a dynamic, deterministic, temperature-driven
```

```
model.  The"
PRINT "  model is written in Microsoft QuickBASIC and developed on a
Zenith 286"
PRINT "  microcomputer.  SBMGMT uses centigrade degree days to calculate
corn "
PRINT "  development, stalk borer development, and movement.  The
boundaries of"
PRINT "  the system are defined as either (1) a grassy noncropped area
(waterway,"
PRINT "  terrace, or field edge) plus the 8 corn rows directly adjacent
to this"
PRINT "  area or (2) a no-tillage corn field of dimensions specified by
the user."
PRINT ""
PRINT "  Hit any key to continue."
DO WHILE INKEY$ = ""
LOOP
CLS 2
PRINT ""
PRINT "  Overview of SBMGMT (cont.)"
PRINT ""
PRINT "       The user can select either the Development portion of the
model or"
PRINT "  the Yield portion of the model.  The Development model predicts
egg"
PRINT "  and movement of larvae out of grasses.  The model assumes that
no"
PRINT "  herbicides have been applied and that the grass is similar in
size to"
PRINT "  smooth brome.  The model also predicts the optimal time period
to "
PRINT "  estimate stalk borer density in the grass, coinciding with 500-
600"
PRINT "  centigrade degree days (CDD).  At this time, stalk borers are
mostly"
PRINT "  third instars.  At this time, tunneling larvae have caused the
grass"
PRINT "  stem to wilt and turn brown, a condition termed 'dead heart'."
PRINT "       The model compares stalk borer populations, damage, and
yields for"
PRINT "  the field with and without the use of insecticides.  The
insecticide "
PRINT "  program is specified by the user.  To aid in timing insecticide
sprays,"
PRINT "  the program will plot projected hatch, movement, and stage of
corn"
PRINT "  development.  Multiple runs are required to compare
modifications in"
PRINT "  cultural practices, such as altering dates for planting and
herbicide"
PRINT "  application.  For multiple runs the program is equipped with an
```

```
editor,"
PRINT "  which allows changes in some or all of the input parameters.  "
PRINT ""
      PRINT "  Hit any key to continue."
      DO WHILE INKEY$ = ""
      LOOP
      CLS 2
      GOTO InstructMenu
   CASE 2
      CLS 2
      PRINT : PRINT
      PRINT SPC(20); "Weather Files"
      PRINT ""
PRINT "                 "
PRINT "       At least one and often two weather files are required to
run SBMGMT."
PRINT "  The first file contains weather data for the year the simulation
is run. "
PRINT "  Weather data in the second file is composed of 20-year average
weather"
PRINT "  for Julian dates 1 through 214.  Nine files containing average
weather for"
PRINT "  the 9 districts in Iowa have been included with the program.
These files"
PRINT "  are denoted as either NW, NC, NE, WC, C, EC, SW, SC, or SE plus
the word"
PRINT "  DATA tacked on the end.  For example the file containing 20-year
average"
PRINT "  weather information for the east central region in Iowa is
ECDATA."
PRINT "       Names of weather files should be specified exactly as
desired, "
PRINT "  including upper and lower case letters (if necessary) and a
drive specifier"
PRINT "  (again, if necessary).  For example, file names, such as Ames86
and"
PRINT "  B:TEMP1.DAT, are appropriate."
      PRINT ""
      PRINT "  Hit any key to continue."
      DO WHILE INKEY$ = ""
      LOOP
      CLS 2
      PRINT "  Weather Files (cont.)"
      PRINT ""
PRINT "       Weather file data must be in the form of :"
PRINT ""
PRINT "          JULIAN DATE, DAILY MAXIMUM, DAILY MINIMUM, RAINFALL"
PRINT ""
PRINT "  For example:"
PRINT "       1,10,-3,0"
PRINT "       2,20, 5,0.3"
```

```
PRINT "       3,32,20,0"
PRINT ""
PRINT "  Temperatures can be entered as fahrenheit or centigrade.  Daily
rainfall"
PRINT "  totals can be entered in inches or centimeters."
PRINT "       Some restrictions apply to these data sets, as required by
Microsoft"
PRINT "  Basic.  Variables must be separated by commas.  Leading blanks
are"
PRINT "  ignored but negative signs must be immediately next to the
number."
PRINT ""
PRINT "           Correct data format:                  Incorrect data
format:"
PRINT "           100, -10, -7,0                         100, - 10,-  7,0"
PRINT "           100, -10,  -7, 0"
      PRINT ""
      PRINT "  Hit any key to continue."
      DO WHILE INKEY$ = ""
      LOOP
      CLS 2
      PRINT "  Weather Files (cont.)"
      PRINT ""
PRINT "       All Julian dates in a data file must be in sequence and
only differ"
PRINT "  by one.  Although data files may contain more than 214 entries
(January 1"
PRINT "  through August 1), the program will read only the first 214
entries."
PRINT "       All data sets must be in ASCII format without higher order
bits"
PRINT "  set.  For details on data set requirements, please review the
Microsoft"
PRINT "  Basic Manual.  SBMGMT does not contain routines for creating
data sets"
PRINT "  because data sets can be most easily created and edited with
available"
PRINT "  programs such as dBase II or Wordstar (in nondocument mode)."
      PRINT ""
      PRINT "  Hit any key to continue."
      DO WHILE INKEY$ = ""
      LOOP
      CLS 2
      GOTO InstructMenu
   CASE 3
      CLS 2
      PRINT ""
      PRINT SPC(20); "Missing Data in Weather Files"
      PRINT ""
PRINT "       The FILEIN subroutine of SBMGMT is able to handle two types
of"
```

```
PRINT "  missing data.  If weather data is not available for either
before a"
PRINT "  given date or after a given date, the program constructs a new
weather"
PRINT "  file composed of available current weather data and average
weather"
PRINT "  data stored in a second file designated by the user.  For
example, if"
PRINT "  the current weather file contains weather data from February 1
to "
PRINT "  May 15 (Julian dates 32 and 135), the current data file is
constructed"
PRINT "  as follows:"
PRINT "                    32, 15, 7, 0"
PRINT "                    33, 20, 13, 0"
PRINT "                    ."
PRINT "                    ."
PRINT "                    133, 72, 56, 0.5"
PRINT "                    134, 77, 59, 0"
PRINT "                    135, 80, 63, 0"
PRINT "  The user specifies the beginning and ending Julian dates
contained in"
PRINT "  the file when prompted.  The program then requests the name of a
file"
PRINT "  containing average weather data."
      PRINT ""
      PRINT "  Hit any Key to continue."
      DO WHILE INKEY$ = ""
      LOOP
      CLS 2
      PRINT "  Missing data (cont.)"
      PRINT ""
PRINT "      Missing data within a current data file must be designated
as '999'."
PRINT "  For example:"
PRINT "                    137, 999, 71, 0"
PRINT "                    138,  85, 63, 1.0"
PRINT "                    139,  82, 64, 999"
PRINT "  The maximum temperature and rainfall total for Julian dates 137
and"
PRINT "  139 are missing in the example.  If the program detects missing
data,"
PRINT "  the program substitutes average weather data for that day.  If
needed,"
PRINT "  the program will prompt for the name of the file containing
average"
PRINT "  weather data."
      PRINT ""
      PRINT "  Hit any key to continue."
      DO WHILE INKEY$ = ""
      LOOP
```

```
        CLS 2
        GOTO InstructMenu
    CASE 4
        CLS 2
        PRINT : PRINT
        PRINT SPC(20); "Model Input and Output"
        PRINT ""
PRINT "     All input, except for weather data, is entered by using the
"
PRINT "  keyboard and entering information when prompted.  See selection
2 and"
PRINT "  3 for information on constructing weather files."
PRINT ""
PRINT "                          INPUT PARAMETERS"
PRINT ""
PRINT "  1.  Names of files containing current and 20-year average
weather"
PRINT "      data; includes Julian date, maximum and minimum
temperatures, and"
PRINT "      rainfall."
PRINT ""
PRINT "  2.  Year of simulation."
PRINT ""
PRINT "  3.  Insect parameters"
PRINT "          a)  density of larvae in grass terrace or waterway"
PRINT "              (larvae/sq. ft.)"
PRINT "          b)  density of larvae in field (larvae/grass clump)"
PRINT "          c)  number of grass clumps per yard of row"
PRINT ""
PRINT "  Hit any key to continue."
DO WHILE INKEY$ = ""
LOOP
CLS 2
PRINT ""
PRINT "  Input parameters (cont.)"
PRINT ""
PRINT "  4.  Field Parameters"
PRINT "          a)  length and width of noncrop area (feet)"
PRINT "          b)  length and width of crop area (no-till situation)
(feet)"
PRINT ""
PRINT "  5.  Crop parameters"
PRINT "          a)  yield potential of the field (bu/acre)"
PRINT "          b)  planting date (Julian day)"
PRINT "          c)  degree days (F) for hybrid to reach maturity"
PRINT "          d)  plant populations (per acre)"
PRINT "          e)  row width (inches)"
PRINT "          f)  soil moisture condition at planting (adequate or
dry)"
PRINT "          g)  price of corn ($/bu)"
PRINT ""
```

```
PRINT "  6.  Pesticides"
PRINT "         a)  Julian date that a grass herbicide is applied"
PRINT "         b)  cost of each insecticide application ($/acre)"
PRINT "         c)  Julian dates for up to three insecticide
applications"
PRINT "         d)  number of row sprayed (4 or 8) for each insecticide
spray"
PRINT ""
PRINT "  Hit any key to continue."
      DO WHILE INKEY$ = ""
      LOOP
      CLS 2
      GOTO InstructMenu
   CASE 5
      CLS 2
   CASE ELSE
      GOTO InstructMenu
   END SELECT
END SUB

'**********************************************************************
SUB Printl (Namel$, Name2$)
'**********************************************************************
'
'This subroutine prints information on stalk borer development, movement
'from grassy areas to corn, and movement induced by herbicide
'application.
'
SHARED Cddsb(), Fddsb(), Phatch#(), Pmove#(), Fmove#(), Sampl%, Samp2%
SHARED Dayl%, DAYL%
PRINT : PRINT SPC(20); "PRINTING EGG HATCH AND LARVAL MOVEMENT."
PRINT
LPRINT SPC(5); "FILE FOR CURRENT WEATHER DATA: "; Namel$; " from"; Dayl%;
LPRINT "to"; DAYL%
LPRINT
LPRINT SPC(5); "FILE FOR 20-YEAR AVERAGE WEATHER DATA: "; Name2$
LPRINT
LPRINT SPC(5); "Sample grass between julian days"; Sampl%; "and"; Samp2%;
LPRINT : LPRINT
LPRINT SPC(5); "            Stalk Borer   Proportion     Proportion
Moving"
LPRINT
LPRINT SPC(5); "Julian      CDD      FDD      Hatched    Grassy Areas    ";
LPRINT "In Field"
LPRINT SPC(5); "  Day"
LPRINT SPC(5);
"________________________________________________________________"
LPRINT
FOR I = 91 TO 212
   LPRINT SPC(5);
   LPRINT USING "  ###   "; I;
```

```
   LPRINT USING "     ####"; Cddsb(I); Fddsb(I);
   LPRINT USING "       #.####"; Phatch#(I);
   LPRINT USING "        #.####"; Pmove#(I); Fmove#(I)
NEXT I
LPRINT SPC(5);
"________________________________________________________________"
LPRINT STRING$(1, 12)
END SUB

'*********************************************************************
SUB Print2 (Nrow, Ppopr)
'*********************************************************************
'
'This subroutine prints out information on corn development and the
'number of larvae that move to the corn from grassy areas and from
'within the field itself.
'
SHARED Cddc(), Cstage() AS SINGLE
SHARED N() AS SINGLE, Healthy(), Acres
SHARED Jplant, Leaf%(), Nsbgl!, Nsbfl!
SHARED Fddc(), Jinsect%(), AppN, An5$, An6$
SHARED PredYld() AS SINGLE, Cost, Price, TotSb()
DIM I AS INTEGER
IF An5$ = "Y" THEN
   PRINT ""
   PRINT SPC(19); "PRINTING CORN GROWTH AND LARVAL NUMBERS."
   LPRINT SPC(5); "Number of stalk borers present in noncrop areas: ";
   LPRINT USING " ###### "; Nsbgl!
   LPRINT
   LPRINT SPC(5); "Number of stalk borers present in field grass: ";
   LPRINT USING " ######.# "; Nsbfl!
   LPRINT SPC(5);
"_____________________________________________________________________"
LPRINT " "
LPRINT SPC(5); "Julian     Corn       Growth stage    No Insecticide";
LPRINT "     Insecticide "
LPRINT SPC(5); " Day    CDD     FDD   Model    Leaf      # of Larvae";
LPRINT "      # of Larvae "
LPRINT SPC(5);
"_____________________________________________________________________"
   LPRINT
   FOR I = Jplant TO 212
      LPRINT SPC(5);
      LPRINT USING "  ###"; I;
      LPRINT USING "  ####.#"; Cddc(I); Fddc(I);
      LPRINT USING "  ##.##"; Cstage(I);
      LPRINT USING "    ## "; Leaf%(I);
      LPRINT USING "      #######.#"; TotSb(1, I);
      LPRINT USING "        #######.#"; TotSb(2, I)
   NEXT I
   LPRINT STRING$(1, 12)
```

```
END IF
Difyld = 0
FOR J = 1 TO Nrow
   Difyld = Difyld + (PredYld(2, J) - PredYld(1, J)) / Nrow
NEXT J
CLS 2
Tcost = Cost*Acres*(Jinsect%(1,2) + Jinsect%(2,2) + Jinsect%(3,2)) / Nrow
Value = Difyld * Price * Acres
Returns = Value - Tcost
IF An6$ = "Y" THEN
   FOR JIN = 1 TO 2
      IF JIN = 1 THEN
         LPRINT SPC(30); "PROGRAM WITHOUT INSECTICIDE"
         LPRINT
      ELSE
         LPRINT SPC(23); "PROGRAM WITH";
         LPRINT USING " # "; AppN;
         LPRINT "INSECTICIDE APPLICATION";
         IF AppN <= 1 THEN
            LPRINT ""
         ELSE
            LPRINT "S"
         END IF
         LPRINT
      END IF
      LPRINT SPC(28); "% DAMAGED PLANTS   GRAIN YIELD, BU/ACRE"
      LPRINT
      FOR J = 1 TO Nrow
         Daml = 100 * (Ppopr - Healthy(JIN, J)) / Ppopr
         LPRINT SPC(20); "Row";
         LPRINT USING " #"; J;
         LPRINT USING "        ###.##"; Daml;
         LPRINT USING "             ####.#"; PredYld(JIN, J)
         LPRINT
      NEXT J
   NEXT JIN
   LPRINT ""
   LPRINT SPC(10); "Comparison of programs with and without insecticide"
   LPRINT ""
   LPRINT SPC(10); "Crop area for each simulation: ";
   LPRINT USING "###.##"; Acres;
   LPRINT " acres"
   LPRINT ""
   LPRINT SPC(10); "Average difference in yield:  ";
   LPRINT USING " ####.##"; Difyld;
   LPRINT " bu/acre"
   LPRINT ""
   LPRINT SPC(10); "Cost of insecticide program:  $";
   LPRINT USING "####.##"; Tcost
   LPRINT ""
   LPRINT SPC(10); "Net returns for designated area:  $";
```

```
   LPRINT USING "####.##"; Returns
   LPRINT STRING$(1, 12)
END IF
CLS 2
FOR JIN = 1 TO 2
   PRINT ""
   IF JIN = 1 THEN
      PRINT SPC(30); "PROGRAM WITHOUT INSECTICIDE"
   ELSE
      PRINT SPC(23); "PROGRAM WITH";
      PRINT USING " # "; AppN;
      PRINT "INSECTICIDE APPLICATION";
      IF AppN <= 1 THEN
         PRINT ""
      ELSE
         PRINT "S"
      END IF
      PRINT ""
   END IF
   PRINT SPC(28); "% DAMAGED PLANTS   GRAIN YIELD, BU/ACRE"
   FOR J = 1 TO Nrow
      Daml = 100 * (Ppopr - Healthy(JIN, J)) / Ppopr
      PRINT SPC(20); "Row";
      PRINT USING " #"; J;
      PRINT USING "        ###.##"; Daml;
      PRINT USING "            ####.#"; PredYld(JIN, J)
   NEXT J
NEXT JIN
PRINT "     Press any key to continue."
DO
LOOP WHILE INKEY$ = ""
CLS 2
PRINT ""
PRINT ""
PRINT SPC(10); "Comparison of programs with and without insecticide:"
PRINT ""
PRINT SPC(10); "Crop area for each simulation: ";
PRINT USING "###.##"; Acres;
PRINT " acres"
PRINT ""
PRINT SPC(10); "Average difference in yield:  ";
PRINT USING " ####.##"; Difyld;
PRINT " bu/acre "
PRINT ""
PRINT SPC(10); "Cost of insecticide program:  $";
PRINT USING "####.##"; Tcost
PRINT ""
PRINT SPC(10); "Net Returns for designated area:  $";
PRINT USING "####.##"; Returns
PRINT ""
PRINT SPC(20); "Hit any key to continue."
```

```
DO
LOOP WHILE INKEY$ = ""
END SUB

'**************************************************************************
FUNCTION Search% (Stage)
'**************************************************************************
SHARED GROW!()
N = 1
DO UNTIL Stage >= GROW!(N, 1) AND Stage < GROW!((N + 1), 1)
   N = N + 1
   IF N = 26 THEN EXIT DO
   LOOP
Search% = GROW!(N, 2)
END FUNCTION

'**************************************************************************
FUNCTION Surv (I, J, Jinsect%())
'**************************************************************************
'
'This function calculates the probability of a larva surviving the
'migration from grass to corn.  The probability of surviving is a
'function of the number of days since an insecticide was applied.
'
DIM S(3)
Low = .5
FOR N = 1 TO 3
   M = I - Jinsect%(N, 1)
   IF M < 0 OR M > 14 OR Jinsect%(N, 2) < J THEN
      S(N) = .5
   ELSEIF M >= 0 AND M < 4 THEN
      S(N) = .1
   ELSEIF M >= 4 AND M < 8 THEN
      S(N) = .2
   ELSE
      S(N) = .35
   END IF
   IF S(N) < Low THEN Low = S(N)
NEXT N
Surv = Low
END FUNCTION

'**************************************************************************
FUNCTION Yield# (JIN, J, Stress, Potyld)
'**************************************************************************
SHARED Injplt() AS SINGLE
'
'This function uses the average rating of the area and the proportion
'of plants injured by stalk borer to calculate yield.
'
Ar# = 0
```

```
Tpinj# = 0
FOR Rate% = 2 TO 6      'Calculation of average rating and plants injured
   Pinj# = 0
   FOR Leaf% = 1 TO 7
      Pinj# = Pinj# + Injplt(JIN, J, Leaf%, Rate%)
   NEXT Leaf%
   Ar# = Ar# + Pinj# * Rate%
   Tpinj# = Tpinj# + Pinj#
NEXT Rate%
Ar# = Ar# + (1 - Tpinj#)
Hyld# = Yloss#(1, Ar#, Stress)          'Yield of healthy plants
Damyld# = 0
FOR Leaf% = 1 TO 7
   FOR Rate% = 2 TO 6
Damyld# = Damyld# + Injplt(JIN,J,Leaf%,Rate%) * Yloss#(Rate%,Ar#,Stress)
NEXT Rate%, Leaf%
Yield# = ((1 - Tpinj#) * Hyld# + Damyld#) * Potyld
END FUNCTION

'***********************************************************************
FUNCTION Yloss# (Rate%, Ar#, Stress)
'***********************************************************************
'
'This function is called by Yield# to calculate the yield contribution,
'as proportion of optimal yield, for a given plant rating, plot average
'rating, and stress condition.
'
IF Stress = 1 THEN                       'Yield under adequate moisture
   Y# = .919 - .0397 * Rate% ^ 2 + .114 * Ar#
ELSE                                     'Yield under drought conditions
   Y# = .997 - .265 * Rate% + .162 * Ar#
END IF
IF ((Rate% = 1) AND (Y# < 1)) THEN Y# = 1
Yloss# = Y#
END FUNCTION
```